PROPLAB-PRO

Version 2.0

High Frequency Radio Propagation Laboratory

USER'S MANUAL

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SECTION 1 - INTRODUCTION

1.1 Introduction to PROPLAB PRO

For years, the ionosphere has been used as a major avenue of communication. The unique ability of the ionosphere to bend and reflect radio waves has been a topic of heavy study for decades. Over the many years since we began studying the ionosphere, we have learned a great deal about the characteristics and true nature of the ionosphere. Many books have been devoted to this subject[1].

Over the last 20 years, computers have been used with ever increasing frequency to study the effects of radio signal refraction - or the bending of radio waves - within the ionosphere. In the last 10 years, personal computers have become significantly more powerful and capable of performing the complex functions necessary to analyze the ionosphere in relative detail. It is then no wonder that we have made many of the major strides in the field of ionospheric radio propagation in this same period of time.

There are many computer programs presently available for predicting such quantities as the Maximum Usable Frequency (or MUF), great-circle paths (or the path travelled by a radio signal from one location to another), and graylines (or the regions where the Sun is either rising or setting). Several of these have advanced features such as the ability to compute signal strengths between two points, or optimum times of transmission.

PROPLAB PRO contains all of these features and many others which have previously only been found on the larger main-frame computers available to researchers and scientists. For example, PROPLAB PRO is the *only* propagation software in the world for IBM or compatible personal computers that will show you the precise behavior of radio signals as they travel through the ionosphere. It effectively simulates radio transmissions into the ionosphere with a high-degree of accuracy by using sophisticated ionospheric ray-tracing techniques.

It is hoped this manual will help teach the reader how to use and interpret the numerous available features of PROPLAB as well as how to better understand the ionosphere.

This manual may therefore serve as both a tutor and a reference. Most, if not all, of the illustrations given in this manual, were generated by the PROPLAB PRO software.

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[1] Ionospheric Radio, Kenneth Davies (1990) Peter Peregrinus Ltd., The Propagation of Radio Waves, K.G. Budden (1985), Cambridge University Press.

SECTION 2 - BACKGROUND

2.1 The Ionosphere and magnetosphere

The ionosphere is that region of our upper atmosphere which lies between about 50 km and several Earth radii. For our purposes, the ionosphere is defined as the region between about 50 km and 1000 km. This is the area where the major effects of signal refraction take place. It also encompasses almost all of the phenomena which can affect radio communications. Figure 2.0 below illustrates the structure of the ionosphere on a quiet summer day.

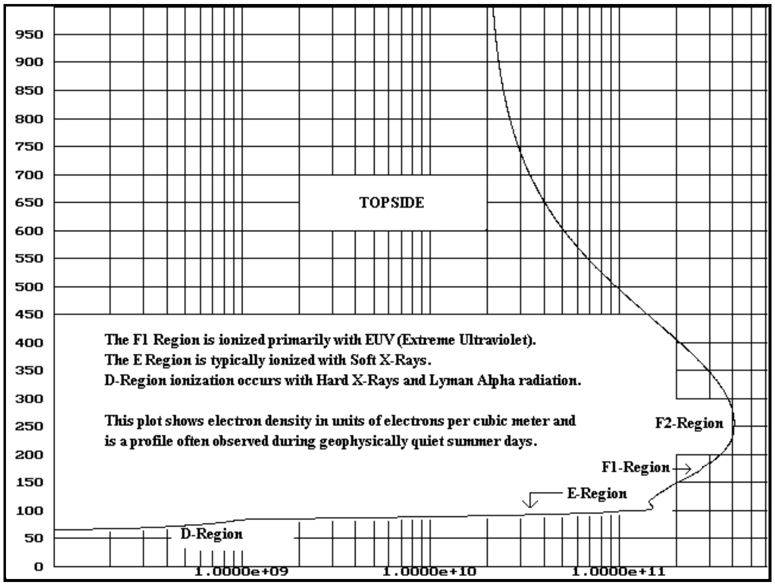

Figure 2.0: *Typical Electron Density Profile for a Summer Day*

The peak electron density of the ionosphere usually occurs in the F region of the ionosphere. The F-region is divided into two regions known as F1 and F2. The F1 region is the lower of the two. Both of these regions are ionized with extreme ultraviolet light (EUV). The F1 layer is not always present in the ionosphere. Often, the F2 layer is large enough to encompass the F1 layer. In Figure 2.0, the exact location of the F1 region is difficult to discern due to the density and spatial extent of ionization in the F2 layer.

The E-region of the ionosphere lies between approximately 90 and 140 km and is a fairly dynamic region of the ionosphere. Sporadic-E, or areas of localized and sporadically intense ionization, occurs between about 100 and 115 km with a peak near 105 km. The E-region is ionized by soft x-ray solar radiation.

The D-region lies between about 50 and 90 km and contains the D-layer as well as another less-influential layer known as the C-layer, or Cosmic Ray layer. The latter is ionized by high-energy cosmic rays which are occasionally observed following strong solar proton flares. The D-layer is ionized with hard x-rays or Lyman Alpha radiation.

Above the peak of the electron density, which usually occurs in the F2 layer, the electron density decreases relatively slowly (exponentially) with altitude. This region is known as the Topside of the ionosphere. Above the topside lies the protonosphere and the plasmasphere, which are not well defined boundaries and stretch for many thousands of kilometers in height.

The ionosphere is strongly dependent on the condition of the geomagnetic field. The geomagnetic field cocoons the Earth and stretches out on the dark-side of the Earth for millions of kilometers. If we could see the magnetic field of the Earth from a distance, it would resemble a comet, with the Earth as the "head".

The solar wind is a stream of charged particles emanating from the Sun. This "wind" blows at speeds of between 250 and 350 kilometers (km) per second under relatively quiet conditions. The magnetic field of the Sun is usually pulled out along with the solar wind. When the solar wind reaches the Earth, the magnetosphere of the Earth is pulled out along with the solar wind. It is this which forms the "cometary" appearance of our magnetic field.

When the solar wind reaches the magnetosphere of our Earth, our magnetosphere deflects much of the solar wind stream around the Earth. The flow of this solar wind over our magnetic field generates a great deal of energy which is (to some extent) stored by the magnetic field of the Earth. Occasionally, this energy is suddenly released. The resulting disturbance is known as a geomagnetic substorm. A geomagnetic storm is made up of many substorms and can have a serious impact on the ionosphere.

Geomagnetic storms are almost always associated with decreases in electron density in the F-region, which results in a lowering of the maximum usable frequency. This decreases the usable bandwidth and can cause difficulties in communicating over long distances. We will discuss this in greater detail later.

2.2 Solar-Terrestrial Relationships

The Sun is an integral part of our environment. We depend on it for life-sustaining light, energy, and heat. It is essential that we have a basic understanding of how the Sun can influence the ionosphere before we can expect to understand the behaviour and character of the ionosphere. This section is devoted to explaining how the sun interacts with our terrestrial environment, and particularly the ionospheric environment.

2.2.1 General Features of the Sun

The Sun lies at an average distance of 149,600,000 kilometers (or 93,500,000 miles) from the Earth. The Sun is about 330,000 times more massive than the Earth and the Moon combined. It has a photospheric temperature of about 5800 degrees Kelvin and a gravitational pull over 333,000 times stronger than here on Earth. The average radius of the Sun is 109 times larger than the radius of the Earth, or about 696,000 km. It takes approximately 27 days for the solar equatorial regions to complete one rotation. We could fit over 1.3 million Earths inside of the Sun.

The Sun is composed of an interior region which lies below the visible photosphere. Above the photosphere lies the chromosphere or lower solar atmosphere. The corona forms the outer atmosphere of the Sun. About 99.9 percent of the Sun is composed of hydrogen and helium, and of these elements, hydrogen is by far the most abundant (92.1%). The photosphere of the Sun represents that region of the solar atmosphere where the gaseous density increases rapidly to the point where features below the boundary of the photosphere appear opaque.

The temperature above the photosphere falls to a value of about 4200 K approximately 5000 km in altitude. Thereafter, the temperature increases to approximately 1 to 3 million degrees Kelvin in the coronal regions.

2.2.2 Solar Activity and Solar Cycles

With the naked (protected) eye, the Sun appears as an almost featureless disk. However, using telescopes, it has been determined that this is not true. The Sun contains many different types of phenomena. Perhaps most significant are the appearance of Sunspots. Sunspots were first discovered by Theophrastus near 325 BC. These dark spots form and disappear over time intervals ranging from less than a day to several months. Sunspots appear dark because the temperature (about 3000 K) within the dark regions is lower than that of the surrounding hotter (and therefore brighter) gas. If a sunspot were removed from the Sun and placed in orbit some distance away from the Sun, it would appear as a very luminous object.

All sunspots (and other features) rotate from east to west. Both the Sun and the Earth rotate in the same direction, and the Earth orbits around the Sun in the same direction as the Sun rotates. The Earth is a solid body and rotates from east to west at the same rate over all of the Earth. The Sun, however, is a gaseous body and rotates faster at the solar equator than at the poles. This differential rotation helps to explain some of the processes occurring on (and inside) the Sun.

One of the most notable features of the Sun is the 11-year cycle of activity that it undergoes. For several hundred years (since about the year 1600), astronomers have been recording the number of sunspots that have been visible on the surface of the Sun. Approximately every 11 years, sunspots increase in number and complexity on the Sun. This 11-year cycle is presently used to help forecast the magnitude of future solar cycles.

Sunspots are associated with strong solar magnetic fields. A strong field within a sunspot may approach 0.4 tesla, or about 4000 gammas. This is approximately 6 to 7 percent of the total strength of our Earth's magnetic field. During the maximum of the 11-year sunspot cycle, the total combined magnetic field strength of all visible spots may exceed the entire strength of our Earth's magnetic field by many times. Sunspot groups are often associated with many individual fields which may intertwine and interact with one another.

Just as a bar magnet has both a north and a south pole, sunspots are also polarized with either positive or negative polarity. Most often, sunspots appear as bipolar groups, or regions where both positive and negative polarities exist. When conditions are right, these opposite polarity magnetic fields can interact and react with one another to produce sudden releases of energy known as solar flares. These explosions of magnetic energy can be observed using special filters on optical telescopes known as Hydrogen-Alpha filters. These filters permit the observation of the solar chromosphere where solar flares originate.

The processes involved in the production of solar flares is not yet well known. Currently, it is believed that flares are related to coronal mass ejections (or CMEs). CMEs are events on the sun where mass is ejected from the Sun. Coronal mass ejections may interfere with the magnetic fields within sunspot regions and trigger solar flares. It is presently believed that this may be a dominating role in flare production. Previously, it was believed flares themselves may have been responsible for producing the CMEs. However, it now appears the opposite may be true: CMEs may occur before the flare is observed, indicating that the CME is responsible for triggering the flare.

A major type of CME which is often observed are known as disappearing filaments (or DSFs). Strings of material are often observed "floating" above the surface of the Sun. These ropes of gas are suspended above the surface of the Sun by magnetic fields. This process results in the cooling of the gas, which makes it appear darker than the brighter (and hotter) photospheric surface. When observed on the limb, the suspension of the gas above the surface of the Sun can be clearly discerned, and the gas is luminous against the darker background of space. Occasionally, one (or some) of the magnetic fields suspending the gas above the solar surface may break free from the surface. This may cause the gas to begin erupting upward and outward from the Sun. This is known as an erupting filament. Some very impressive erupting filaments have been observed as limb events on the Sun. When observed against the brighter photospheric surface, the dark string of material within the erupting filament simply disappears. From this follows the term, "disappearing filament."

Filaments (and other coronal mass ejections related to the more energetic solar flaring processes), are capable of spewing out mass from the Sun that may quickly travel the large distance from the Sun to the Earth. These disturbances are often travelling at speeds significantly greater than the background speed of the solar wind. When this occurs, a shockwave (not unlike the shockwaves that are formed by supersonic aircraft) may form at the front of the disturbance. Within 2 or 3 days, this material may arrive at the Earth and slam into the Earth's magnetosphere at speeds as high as 7,200,000 kilometers an hour (or 4,500,000 miles per hour, or 2,000 kilometers per second). The magnetosphere responds to this sudden increase in solar wind speed (and pressure) by springing inward or being suddenly compressed. This can be observed in space (and on the ground) by magnetometers which are capable of measuring the strength of the Earth's magnetic field. Compression of our magnetosphere causes the strength of the magnetic field to increase. This sudden enhancement in the strength of the magnetic field is known as a sudden impulse (or SI). When it is associated with the sudden occurrence of geomagnetic storming, it is known as a sudden storm commencement (or SSC). Strong interplanetary disturbances can make it difficult for satellite controllers to control their satellites. Uncontrolled tumbling of satellites can occur. Satellite surfaces may be electrically charged to levels which may cause small discharges within the satellites (and thereby damage some of the electronics).

2.2.3 Flare Rating System

Flares are rated in two different ways. The first method was used earlier this century and is still in wide use today. It involves measuring the brightness of the flare in the light of hydrogen-alpha, and measuring the size of the flaring area. This rating system is composed of a numerical digit and a letter, corresponding to the measured optical size of the flare and the brightness of the event, respectively.

Digits are defined as follow and represent the corrected area of the flare in heliospheric square degrees when the flare is at its maximum brightness in H-Alpha:

S - Subflare (associated with an area <= 2.0 square degrees).
1 - Importance 1 (2.1 <= area <= 5.1 square degrees).
2 - Importance 2 (5.2 <= area <= 12.4 square degrees).
3 - Importance 3 (12.5 <= area <= 24.7 square degrees).
4 - Importance 4 (area >= 24.8 square degrees).

The letter which defines the brightness of the flare, at the maximum phase of the flare, is defined as follows:

F = Faint.
N = Normal.
B = Brilliant.

All flare locations are given in heliographic longitude, which is a done by measuring the distance of the flaring site from the rotational axis of the solar poles, relative to the limbs of the Sun. For example, a location of S20E90 refers to a position 20 degrees south of the solar rotational equator and directly on the eastern limb. A location of N40W00 refers to a position 40 degrees north of the equator and exactly on the central meridian, or the longitude line which cuts both through the center of the Sun and through the rotational poles (from the northern pole to the southern pole) as observed from the Earth.

The second rating system is less subjective and depends on the measured brightness of the soft-xray emissions in the wavelength band 1 to 8 Angstroms, as observed by Earth-orbiting satellites such as GOES-6 and/or GOES-7 (Geostationary Operational Environmental Satellites [or GOES]). This system was initiated on 01 January 1969 and ranks solar activity by its peak x-ray intensity. This classification method offers two distinct advantages compared with the standard optical classification system: it gives a better measure of the geophysical significance of solar activity, and it provides an objective means of classifying geophysically significant activity, regardless of its location on the solar disk or near the solar limb. This rating system is described as follows (all x-ray measurements are in Watts per square meter):

A		Intensity <	10^{-7}
B	10^{-7}	<= Intensity <	10^{-6}
C	10^{-6}	<= Intensity <	10^{-5}
M	10^{-5}	<= Intensity <	10^{-4}
X	10^{-4}	<= Intensity	

The letter designates the order of magnitude of the peak x-ray value observed. The number following the letter is the multiplicative factor. For example, a M3.2 event indicates an x-ray burst with a peak flux of 3.2×10^{-5} Watts per square meter (Wm^{-2}).

The PROPLAB software will accept, as input, the peak magnitude of the x-rays observed during solar flares to compute circuit quality during flare activity. The flare rating system which should be used is this one employed for soft x-rays above. Sources for this information are given later in this manual.

2.3 Geomagnetic Indices

It is useful to quantify the degree of magnetic disturbance observed each day over various regions of the Earth, or on a global basis. Numerous different types of indices have been developed and used over the years.[2] Most magnetic observatories determine local indices. The local indices are then used to compute the global indices. The most popular indices presently used to measure levels of geomagnetic activity are known as the A and K indices. Of these, PROPLAB only uses the A-index, although knowledge of how the A-index is derived from the K-index is useful.

2.3.1 The Geomagnetic K-Index

The K-index is a value ranging from 0 to 9 and indicates the magnitude of irregular variations occurring with the geomagnetic field over a period of 3 hours, using Universal Time (UT). For example, one digit is used to define the level of activity occurring between 0000 and 0300 UTC. Another digit is used to describe activity levels between 0300 and 0600

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[2] "Polar Magnetic Substorms", Review of Geophys. Space Physics, **10**, page 157. "Introduction to Geomagnetism", Parkinson W.D., Scottish Academic Press Ltd., Edinburgh).

UTC, and so on throughout the UTC day.

Since the level of magnetic disturbance is usually higher in the higher latitude regions, each observatory is assigned their own rating scale to account for the level of activity observed at each observatory. For example, an equatorial station may observe small field variations on the order of several gammas defining a "quiet" interval. On the other hand, it may be normal for a high latitude station to observe field variations on the order of several tens of gammas defining a quiet interval for that region. For this reason, each station is assigned their own rating scale. However, all stations scale their measurements so that their K-index values fall within the 0 to 9 range.

The range used, 0 to 9, defines the level of activity observed, from dead-quiet (0), to extremely disturbed (9). The amplitude range of the magnetic field during a given 3-hour interval (that is, the maximum value minus the minimum observed value, in gammas) is used to determine the K-index value.

The K-index is quasi-logarithmic and open ended. Each observatory uses a look-up table created for that specific location, to convert an amplitude range into an associated K-index value. The table given below shows the look-up table for a typical middle-latitude magnetic observatory.

K	0	1	2	3	4	5	6	7	8	9
a_k	0	3	7	15	27	48	80	140	240	400

The "a_k" indices for a particular station may be converted into units of gammas by multiplying them by a station-specific factor. This factor can be found by dividing the stations minimum value for a K-index of 9 (in this case, 400) by 250. So for this case, a K-index of 5 would be associated with an a_k index of 27, which would convert to a magnetic field variation of 27 x 1.6 (400 / 250 = 1.6) = 77 gammas. Another term commonly used (and coming into greater usage), is the nanotesla (nT). One gamma is equivalent to one nanotesla.

The planetary K-index values for a given 3-hour interval are obtained by simply computing the numerical mean of all of the K-indices for all known stations, for each 3-hour interval.

2.3.2 The Geomagnetic A-Index

This index is based on the K-index as follows. Each K-index for every station is associated with a given a_k index as previously described. The A-index for a particular station is simply the average of the eight a_k-indices for that UTC day. For example, eight K-indices given as "3445 4332" would correspond to an A-index of 23. This is done by computing the average of the associated eight a_k indices as follows:

$$(15 + 27 + 27 + 48 + 27 + 15 + 15 + 7) / 8 = 22.6, \text{ or } 23.$$

This simple method of computing the A-indices (and the table given above) can be applied to most middle latitude regions. High latitude stations will be associated with a different range index - a_k (one which spans larger ranges).

The PROPLAB software will accept, as input, the A-index value. The A-index values broadcast by radio stations WWV and WWVH (on HF frequencies 2.5, 5.0, 10, 15, and 20 MHz) at 18 minutes past each hour, can be input into the software. Alternatively, for 3-hour values, the K-index value given in this same message can be converted into an equivalent A-index value (as described above), and then input into the software. This may, under rapidly changing circumstances, result in more accurate results.

2.4 The Auroral Zones

The auroral zones can be defined as those areas of the Earth where visible aurora occurs overhead. They typically occur within an oval-shaped ring centered approximately on the north and sound magnetic poles. Two zones of aurorae are therefore visible on the Earth: one near the north magnetic pole, and the other near the south magnetic pole. Since the northern magnetic pole lies closest to North America, Canadian regions are well-placed for observing periods of auroral activity. In the northern hemisphere, this activity is known to the public as the "northern lights" or the "aurora borealis". In the southern hemisphere, it is known as the "aurora australis".

The Solar Terrestrial Dispatch has developed a Professional Dynamic Auroral Oval Simulator for IBM compatible PC computers running MSDOS, which will explicitly delineate the location of the auroral ovals for any given hour and level of geomagnetic activity. It will also show you where in the sky to look for aurorae, and will simulate the intensity and spatial extent of activity, visible from any position on the Earth. For more information, write us regarding this software package.

Auroral activity is the result of atmospheric atoms and molecules being excited by energetic electrons and ions beamed into the ionosphere. During geomagnetic substorming, for example, processes beyond the scope of this manual excite electrons and ions in the magnetosphere and accelerate them. These particles follow the magnetic field lines and therefore penetrate mostly into the higher latitudes where the field lines make sharp angles to the surface of the Earth. As they penetrate into the ionosphere, they reach sufficiently dense regions of the atmosphere to collide with various atmospheric molecules and atoms. In the collision, the energy released excites the atoms to higher energy states. When these atoms drop back toward their more stable energy states, they release a photon of light that is unique in color (or wavelength) for that particular atom. It is this light which we see as auroral activity.

Auroral activity can occur in a variety of colors and patterns. Emitted wavelengths can range from radio to x-rays. As well as visible aurora, there are infrared aurora, ultraviolet aurora, and x-ray aurora. Visible aurora can occur in a variety of colors. A few of the more important colors observed are green and red (at 5577 Angstroms and 6300 Angstroms respectively) produced by excitation of oxygen, as well as colors from molecular bands of singly ionized N_2 molecules. Most activity appears as greenish-blue or greyish colors.

2.4.1 Importance to HF Propagation

Most radio amateurs and even some professional broadcasters do not understand the significance of the auroral zones in radio propagation. The auroral zone is a major region of ionospheric instability and can result in significant signal degradation affecting frequencies from the ELF to the VHF/UHF bands. Failure to consider this region of ionospheric instability can result in significantly flawed and inaccurate propagation predictions and circuit analyses.

The auroral zones are regions where electrons penetrate and deposit energy into the ionosphere. Electrons with energy levels between approximately 1 and about 20 or 30 keV are responsible for most of the ionization above 100 km. Of this ionization, a good portion of the total ionization occurs at the lower-levels of the ionosphere near 100 km, although significant instabilities can exist above this level as well.

On an average quiet day, the auroral zone is situated near a geomagnetic latitude of 67 degrees. However, the auroral zone is a dynamic region capable of rapid expansion and intensification during substorm periods. Equatorward migration of the auroral ovals is a common feature of auroral substorms. During enhanced periods of geomagnetic activity, the auroral zone expands equatorward to encompass areas of the world which are not part of the quiet-time auroral zone. This is one reason why some transatlantic circuits may experience complete signal loss during geomagnetic storms while others are capable of conducting reasonable communications. The quality of the signal depends, to a fairly large extent, on the position and level of activity of the auroral zones.

For these reasons, most radio propagation software do not take the auroral zone degradation into consideration. This is unfortunate, since many thousands of people who rely on transauroral (paths which cross into or through the auroral zone) or transpolar paths for communicating cannot reliably use this propagation software to help determine signal quality.

Moreover, since the auroral ovals are offset from the rotational poles of the Earth, the location of the auroral zones is continually changing and is difficult to track. This is another reason why most propagation programs cannot (or fail to) account for the auroral zone degradation, even though this is the area of the signal path where most signals will be degraded most heavily.

PROPLAB is based on the results of scientific research and uses proven algorithms for computing the location of the auroral zones for any time of day, and any level of geomagnetic activity. The geomagnetic A-Index is the only parameter required (aside from the date and time) to compute the position of the auroral zones. PROPLAB is therefore better equipped to analyze and assess signal degradation through the auroral zones than many other propagation software packages.

2.4.2 Auroral Phenomena

Auroral activity can produce several different types of phenomena, all of which can influence radio communications. The enhanced ionization can absorb radio signals. This type of phenomenon is known as auroral absorption. Sporadic-E is common within the auroral zone, particularly during geomagnetic and auroral storms. Sporadic-E within the auroral zone is known as auroral sporadic-E.

Auroral absorption (or AA) is a widely varying and almost completely unpredictable consequence of auroral activity. It can fluctuate widely both in time and space. The maximum occurrence of auroral absorption appears to be just equatorward of the maximum level of visible auroral activity. It also maximizes in mid-morning at a fixed location. It can produce very poor to useless propagation between two points on a transauroral circuit.

Auroral sporadic-E, when associated with geomagnetic storming, is also known as "storm sporadic-E", or storm E_s. The occurrence of a thick storm E_s layer is known as night E and is not uncommon in the higher latitude regions during local nighttime. This type of activity also varies widely in time and space, and can enhanced E-layer ionization by a substantial amount. Often, the intense ionization observed with this type of activity may be strong enough to reflect radio signals many times higher than usual. It can therefore be a useful tool for propagating over longer distances using frequencies in the higher HF or even the VHF bands - frequencies which would normally simply penetrate the ionosphere.

Electron density gradients within the auroral zones can vary significantly. Horizontal gradients can reflect radio signals in horizontal directions. Horizontal refraction causes non-great-circle-path propagation. This type of phenomenon is fairly common during disturbed geomagnetic and auroral periods in the auroral zones.

PROPLAB is unable to consider each of these differing types of phenomena individually. The main reason for this is the high level of unpredictability which exists for these types of activity. Instead, PROPLAB attempts to lump all of these differing types of activity together to average their effects. It would also be necessary to input several different types of data into the software for it to reliably take this activity into consideration. Aside from being unnecessary, the required inputs would be difficult for the average radio communicator to obtain. Reasonable accuracy is obtained from the software without requiring these inputs.

2.5 Polar Cap Absorption (PCA)

Polar Cap Absorption is the result of intense ionization produced by energetic protons. The protons originate from a class of large solar flares known as proton flares. These types of flares successfully accelerate protons to a good fraction of the speed of light. When these protons reach Earth only minutes to hours later, they spiral around and down the magnetic field lines of the Earth and penetrate into the atmosphere. The high energy of these protons permits them to penetrate relatively deeply before being stopped about 40 to 80 kilometers high. Some particularly powerful flares are capable of throwing out protons with energies in the GeV range (most are between 1 and 100 MeV in energy). These very high energy particles may penetrate much deeper than usual and produce what is known as a Ground Level Event (or GLE) where neutron monitors at ground level experience sudden increases in neutron levels brought about by the deep penetration of these high-energy particles.

PCA's typically last anywhere from about an hour to several days, with an average of around 24 to 36 hours. The intense ionization of the lower ionosphere results in heavy absorption of HF radio signals. The absorption associated with PCA is measured by an instrument known as a riometer (or relative ionospheric opacity meter)[3]. This is basically a radio receiver tuned to receive galactic radio noise on a frequency of about 30 MHz using a vertically directed antenna. A higher frequency would be useful to avoid deviative effects, but on higher frequencies galactic noise levels and ionospheric absorption levels decrease. On a frequency of about 30 MHz, absorption changes of about 0.1 dB can be reliably measured.

To give an idea of how devastating PCA can be, consider what might happen to a signal if the PCA measured over a polar region was 13 dB. This would produce attenuation of approximately 170 dB for a 10 MHz signal reflected from the F-layer. This is sufficient to produce complete signal loss for lower-power (non-commercial) transmissions and very heavy attenuation of signals even from the large and powerful commercial transmitters.

PCA appears first over the polar regions. It then expands equatorward to a magnetic latitude of approximately 65 degrees. The latitude where the ionization produced by the incoming protons subsides, is known as the cutoff latitude. PCA therefore covers the entire polar region down to about a geomagnetic latitude of 65 degrees. This can significantly impact transpolar and even some transauroral circuits.

PCA is not related to auroral activity or geomagnetic storming. Flares which produce

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[3] "The riometer – a device for the continuous measurement of ionospheric absorption", Proc. I.R.E., **47**, page 315.

proton events are almost always associated with coronal mass ejections which can often have a dramatic geophysical impact. However, since the protons travel at much higher velocities than the flare-related shockwave, the protons usually result in PCA for between 24 to 36 hours before the flare-related interplanetary shock reaches the Earth. After the shock front passes the Earth, the density of the high energy protons gradually diminish toward pre-event background levels. PCA therefore usually ends a few hours after the arrival of the main shocked disturbance. However, the level of geomagnetic storming which follows the shocked disturbance is frequently strong enough to maintain very poor to near-useless propagation over the polar regions.

PROPLAB will take polar cap absorption into consideration when computing signal quality values between two geographical points. The level of signal degradation is dependent on signal power, and (perhaps more importantly), signal frequency. Higher frequencies experience less absorption than lower frequency signals during PCA. However, higher frequencies also penetrate the refracting ionospheric layers more easily than lower frequencies. If propagation through the polar regions during PCA is required, it may therefore be wisest to use high transmission powers on frequencies close to the maximum usable frequency. PCA does not significantly alter the refractive nature of the ionosphere. Since most of the ionization and absorption associated with PCA occurs below the E-region (which is the first major refracting layer of the ionosphere), most signals still refract in the same manner as would occur if PCA was not present.

PCA follows a diurnal pattern. Polar cap absorption is strongest during the day and weakest at night. However, the difference between daytime absorption and nighttime absorption is small (only about 2 dB). If PCA is relatively strong (ex. above 4 or 5 dB), this difference in daytime and nighttime absorption levels may not be significant enough to give any better signal performance.

2.6 Ionospheric Radio Propagation

Most ionospheric disturbances have degratory effects on radio communications. However, this is not always true. For example, strong signal absorption during a major flare may completely absorb HF signals and enhance signals in the VHF bands. Polar Cap Absorption may devastate interfering transpolar signals and thereby enhance wanted signals from other less-affected paths. Similarly, blanketing sporadic-E can be responsible for blacking out communications on a wide swath of the available HF bands, while providing improved propagation and greater range for others. PROPLAB gives you the ability to determine how to make the best use of your resources during ionospheric disturbances of a wide variety. However, we must first understand some of the more basic fundamentals of radio propagation through the ionosphere.

2.6.1 Ionospheric Reflection and Refraction

Reflection and refraction are important concepts which must be understood before ionospheric radio propagation can be understood to any degree of usefulness. To help explore these concepts, it is useful to adopt the idea of a ray (or single beam) of light, and what happens to a ray of light as it strikes (or passes through) various types of material.

If a ray of light strikes a highly polished surface, such as a polished chrome surface, the rays of light that fall upon the surface are reflected. No light passes into or through the chrome material due to the opaque nature of the polished metal. More accurately, if a ray strikes a polished surface at an angle of 5 degrees, the reflected ray will also make an angle of 5 degrees away from the surface of the polished material. Likewise, if a ray of light strikes a mirror at a 90 degree angle (perpendicular to the surface of the mirror), the reflected ray will completely reverse direction and bounce right back along the same path that the incoming ray took. This is why it is possible to see yourself in a mirror.

This same principle applies to almost all polished surfaces, whether opaque or not. For example, it is possible to see your reflection in a store window, yet people inside the store can look out, *through* the window. Reflected rays are well-behaved and easily computed. Refracted rays are more difficult.

Refraction, in a practical sense, is the process of "bending" something. Although light travels in a straight line, light can be bent if it travels through material of varying densities. For example, if you take a pencil and stick it into a bowl of water at an angle, the pencil will appear to bend at the boundary between the air and the water, even though in reality the pencil is solid and straight. Likewise, a ray of light which strikes water at an angle will appear to change direction or bend, at the boundary between the air and the water. The reason the pencil appears to bend is because the light at the boundary between the air and the water changes direction, or *refracts*.

In reality, a ray which strikes a surface which is not totally opaque may both reflect and refract the ray. Consider, for example, what happens with the bowl of water. If the surface of the water is undisturbed, it is possible to see reflections in the water (such as your face). At the same time, it is possible to see a dime that has been placed at the bottom of the bowl. Rays of light are both reflected from the surface of the water, permitting you to see your reflection, and rays of light are refracted into the water and reflected back, permitting you to see the dime.

The degree with which a ray of light is refracted depends on the speed of light within the material where refraction takes place compared to the speed of light within the material where the ray is originating. It also depends on the wavelength of the light that is passing between the two materials. The speed of light within a material depends on the density of the material through which the light is travelling.

Light always travels more slowly through a material than it does in a vacuum. The ratio of the two speeds is equal to a quantity known as the *index of refraction*. Thus, the speed of light (v) in a material having an index of refraction (n) is given by:

$$v = c / n, \quad \text{or} \quad n = c / v$$

When light passes from one material to another, its frequency does not change for the following reason. When light interacts with matter, the electrons in the material absorb energy from the light and undergo vibration motion with the same frequency as the light. This motion causes reradiation of the energy with the same frequency. Hence, since the speed of light in a material is equal to the wavelength of the light (w) multiplied by the frequency ($v = w \times f$), when the speed of light is less than the speed in a vacuum (c), the wavelength of the light is also correspondingly reduced. Thus the wavelength of light in a material is less than the wavelength of the same light in a vacuum.

Rays which strike a surface such as water at a shallow angle might not experience any refraction at all. For every refractive material, there is an angle known as the *critical angle* where total internal reflection occurs. This process can be important in radio communications where signals may, for example, strike a highly-dense sporadic-E layer and experience total reflection. Rays which strike the material at angles of incidence smaller than the critical angle are refracted, while rays which strike the material at angles larger than the critical angle are totally reflected.

The idea of total internal reflection can be understood by examining what happens when light passes through a Porro prism (see Figure 2.1). A Porro prism is a triangular slab of glass. When light passes perpendicularly through one of the prisms sides, the ray of light does not change direction but passes undeviated straight into the glass. However, when the light reaches the other side of the prism, it strikes that boundary between the air and the glass at a 45 degree angle. For a glass/air boundary, the critical angle is 42 degrees. Since the angle of incidence at this boundary is larger than the critical angle, all of the light is totally reflected toward the other side of the prism. The same principle applies when the ray of light strikes the second side of the prism. Since the ray also strikes this second side at a 45 degree angle, total reflection occurs again, causing the light to strike the same surface that it first passed through, in a direction opposite and parallel to the emergent ray.

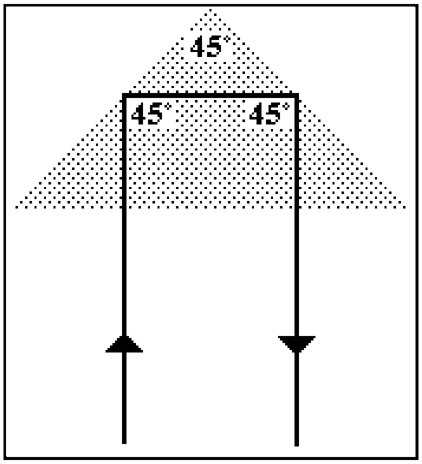


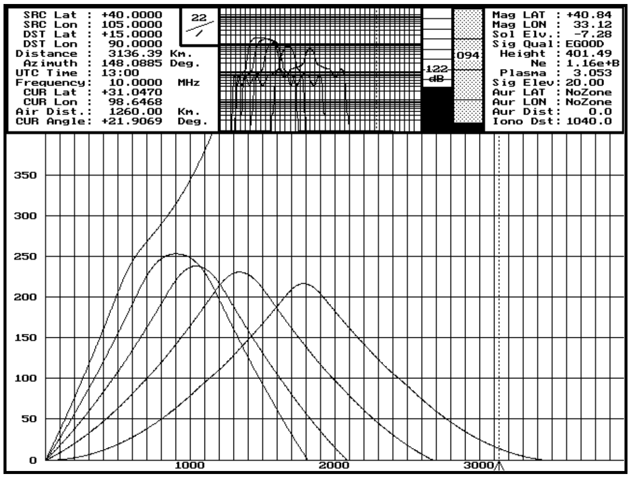
Figure 2.1: *Total Internal Reflection in a Porro Prism*

In order to understand how radio signals are refracted in the ionosphere, it is necessary to have an understanding of the radio refractive index of the ionosphere. Sir Edward Appleton is usually the person to which the radio refractive index is attributed. Appleton was responsible for much of the work which led to the computation of the radio refractive index. It is therefore popularly known as the Appleton formula. Contributions by others have also led to modified names, such as the Appleton-Lassen formula or the Appleton-Hartree formula. Here, we will refer to it as the Appleton formula.

The ionosphere is composed mostly of electrons and ions. The heavier ions do not influence the refractive nature of the ionosphere as much as the electrons. For this reason, considering only the electrons is accurate enough when considering the refractive index of the ionosphere.

As was mentioned previously, glass refracts rays of light because glass is denser than air. Likewise, a ray of light in open space is refracted when it penetrates into our denser atmosphere. The same process applies to refraction of radio waves within the ionosphere. Radio waves are simply low-frequency (or long-wavelength) rays of light.

When a ray penetrates into the ionosphere, the electron density increases rapidly with height until a maximum is reached approximately 250 to 400 km high. As the ray penetrates more deeply into the ionosphere, the increased electron density causes the ray to begin refracting. The degree of refraction which occurs depends on the maximum electron density observed as the ray travels through the ionosphere, and the frequency (or wavelength) of the ray. Lower frequency (or longer wavelengths) encounter greater refraction than rays with higher frequencies (or smaller wavelengths).



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 SRC Lon  : 105.0000
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 DST Lon  :  90.0000
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 Azimuth  : 148.0885 Deg.
UTC Time  : 13:00
Frequency:  10.0000   MHz
 CUR Lat  : +31.0470
 CUR Lon  :  98.6468
Air Dist.:  1260.00   Km.
CUR Angle: +21.9069   Deg.
```

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Mag LON  :  33.12
Sol Elv.:  -7.28
Sig Qual:EGOOD
 Height  :401.49
      Ne :1.16e+B
 Plasma  : 3.053
Sig Elev:20.00
Aur LAT  :NoZone
Aur LON  :NoZone
Aur Dist:    0.0
Iono Dst:1040.0
```

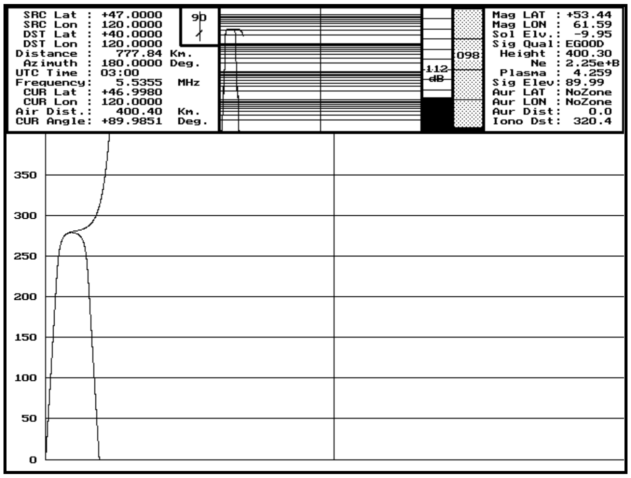
Figure 2.2: *Rays Traced through the Ionosphere*

Consider the example given in Figure 2.2, where a radio ray with a frequency of 10 MHz is transmitted through the ionosphere with a starting transmission elevation angle of 0 degrees. This corresponds to the ray which propagates the farthest and is directed toward the horizon. Details regarding the contents of this figure are given later in this manual. All of the values at the bottom of the figure (from left to right) are ground distances from the origin at the left side of the screen, in kilometers. The numbers from top to bottom on the left side of the figure correspond to altitude above ground, again in kilometers. The bottom panel shows the rays which correspond to transmission elevation angles of 0, 5, 10, 15, and 20 degrees above the horizon. The upper central panel with the logarithmic scale shows the electron density of each of these rays as they pass through the ionosphere. The upper central panel vertical tick marks denote the same distance scale as shown in the large lower panel. The electron density trace farthest from the origin (in the upper central panel) therefore corresponds to the ray with the zero-degree elevation angle in the lower panel. In this example, the ray with lowest angle of transmission (zero degrees) penetrates into the ionosphere where the electron density begins to increase. As the density increases the ray begins to show signs of being refracted. When the ray reaches a height of approximately 200 km, the electron density begins to increase more rapidly along with a corresponding increase in the refractive index. This causes the ray to bend more rapidly until a point is reached where reflection occurs. The ray then begins a downward descent. As the ray begins to descend, the electron density decreases which causes the ray to begin refracting again, only this time in a direction toward the ground. As the ray falls further, the level of refraction decreases until the ray finally penetrates the lower boundary of the ionosphere. At that point, the ray simply travels a straight line until it reaches the ground over 3,400 kilometers from the transmission point.

The last ray traced in the above example is transmitted at an elevation angle of 20 degrees above the horizon. It shows that as the elevation angle is increased, it becomes increasingly difficult for the signal to return to the Earth through the process of refraction. In this case, the signal did refract, but did not refract enough to return to the Earth.

2.6.2 Ionospheric Critical Frequencies and Heights

A great deal of information can be discerned through the study of signals that are transmitted and reflected vertically from the ionosphere. Ionosondes are used for this purpose. There are many ionospheric sounding stations around the world. Most of these stations are equipped with radio equipment designed to transmit signal pulses vertically and listen for echoes. The principles are very similar to those that allow radar guns to work. A signal is transmitted vertically into the ionosphere at a specific frequency. As the signal passes into the ionosphere, it is reflected back to the transmitting station where a receiver records the characteristics and time required for the reflected pulse to return. The ionosonde then transmits another signal pulse at a slightly higher frequency and listens for the return of that pulse. This process repeats in rapid succession with gradually increasing frequencies. The frequency is sweeped from low to high frequencies.



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SRC Lon  : 120.0000
DST Lat  : +40.0000
DST Lon  : 120.0000
Distance :   777.84 Km.
Azimuth  : 180.0000 Deg.
UTC Time : 03:00
Frequency:   5.5355  MHz
CUR Lat  : +46.9980
CUR Lon  : 120.0000
Air Dist.:   400.40  Km.
CUR Angle: +89.9851  Deg.
```

```
Mag LAT  : +53.44
Mag LON  :  61.59
Sol Elv. :  -9.95
Sig Qual: EGOOD
Height   : 400.30
Ne       : 2.25e+B
Plasma   :  4.259
Sig Elev: 89.99
Aur LAT  : NoZone
Aur LON  : NoZone
Aur Dist:     0.0
Iono Dst:   320.4
```

Figure 2.3: *Penetration at the critical frequency*

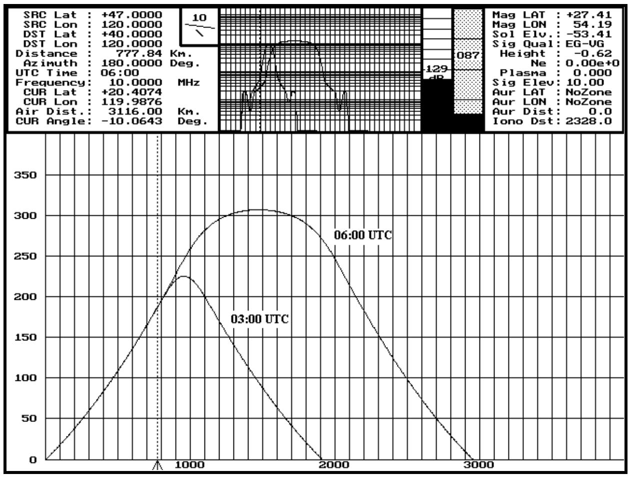
As the frequency increases, a point will be reached where the ionosphere will fail to return a signal. This penetration frequency is also known as the *critical frequency* and represents the maximum frequency that can be ionospherically returned by a vertically propagated signal. Figure 2.3 shows two rays being transmitted at an 89.99 degree angle (essentially vertical, but slightly offset from 90 degrees so we can observe the ray behaviour more clearly). The horizontal scale used is two kilometers in distance. The vertical line down the middle of the figure represents the

1 kilometer mark. In this example, the two rays were offset by slightly different frequencies using the Sweep Frequency function of PROPLAB. The ray which returns to the ground uses a frequency of 5.5350 MHz, which is very close to the critical frequency of 5.5352 MHz. Since the frequency of the ray is slightly lower than the critical frequency, the ionosphere is able to reflect the ray back to the ground. The other ray in the figure is transmitted at the same angle of elevation, but offset slightly in frequency to 5.5355 MHz. Since this ray is slightly above the critical frequency, the ray penetrates the ionosphere and escapes into space.

Critical frequencies are very important in the study of radio propagation. They are used to determine maximum usable frequencies for obliquely propagated radio waves, and can be used in many other ways to help determine other ionospheric quantities as well as the general condition of the ionosphere.

Each ionospheric layer (the E, F1, and F2 layers) has its own critical frequency. Since the maximum electron density usually occurs in the F2 layer, this layer is usually used to determine the maximum usable frequency, or the frequency beyond which signals penetrate the ionosphere altogether. The critical frequency of the E layer is denoted: foE. Similarly, the critical frequencies of the F1 and F2 layers are denoted: foF1 and foF2. It is important to remember that a critical frequency always refers to signals that are directed straight up, toward the zenith. Another frequently used term is the *plasma frequency*, which is simply the critical frequency of a section of ionospheric plasma. This is discussed in greater detail later.

Each ionospheric layer critical frequency occurs at a specific height that varies throughout the day. For example, the critical frequency of the E-layer usually resides near 105 kilometers in height, while the critical frequency of the F2-layer lies between approximately 240 and 350 kilometers in height. Since the critical frequency refers to the location where maximum refraction occurs, it also corresponds to the location where the electron density is a maximum for that region (or layer) of the ionosphere.



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 SRC Lon  : 120.0000
 DST Lat  : +40.0000
 DST Lon  : 120.0000
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 Azimuth  : 180.0000 Deg.
UTC Time  : 06:00
Frequency:  10.0000   MHz
 CUR Lat  : +20.4074
 CUR Lon  : 119.9876
Air Dist.:  3116.00   Km.
CUR Angle: -10.0643   Deg.
```

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Mag LAT  : +27.41
Mag LON  :  54.19
Sol Elv.: -53.41
Sig Qual: EG-VG
 Height  :  -0.62
     Ne  : 0.00e+0
 Plasma  :  0.000
Sig Elev: 10.00
Aur LAT  : NoZone
Aur LON  : NoZone
Aur Dist:    0.0
Iono Dst: 2328.0
```

Figure 2.4: *Propagation to greater distances by raising the height of maximum electron density*

The height of maximum electron density for the various layers of interest are denoted: hmD (for the D-layer), hmE (for the E-layer), hmF1 (for the F1 layer), and hmF2 (for the F2 layer). For long-distance communications, the F2-layer is usually the controlling layer. Through simple geometry, it can be shown that signals can travel greater distances as the height of maximum electron density increases. In Figure 2.4, two rays are traced at different times of the day. The first ray is traced at 03:00 UTC and uses the same frequency and angle of elevation as the second ray, traced three hours later at 06:00 UTC. During this 3-

hour period of time, the height of maximum electron density in the F2 region increases by approximately 50 km. This allows the signal to travel almost 1,000 kilometers farther. This is one reason why propagation improves after sunset. The electron density in the lower regions disappears which permits easier access to the F2-region, which is still strongly ionized and capable of reflecting higher frequency signals over long distances. One of the disadvantages of night-sector propagation is the reduction in critical frequencies. As the evening spreads into night, the F2-layer slowly erodes and becomes less capable of reflecting higher frequencies (in other words, the critical F2-layer frequency [or foF2] decreases). The critical F2-layer frequency usually reaches a minimum in the hours just before sunrise.

Those familiar with ionospheric radio signal propagation may realize that radio signals are split into two component waves: an ordinary wave and an extraordinary wave. Signals are split into these component parts by the Earth's magnetic field. PROPLAB ignores this splitting effect and shows you only the ray paths of the ordinary waves. Inclusion of calculations for the extraordinary wave would require a significantly higher number of complex calculations that would make even many state-of-the-art computers choke. For this reason, only the ordinary waves are modeled in PROPLAB. This does not limit or diminish the capabilities or accuracy of PROPLAB to any significant degree.

2.6.3 The International Reference Ionosphere

The International Reference Ionosphere (or IRI) is a collection of electron density height profiles that are used within computer code to generate realistic profiles of the ionosphere. The IRI references one of two different models developed by two organizations: URSI, and the CCIR. Both of these models can be used within the IRI code through the use of numerical coefficients to describe the world-wide behaviour of ionospheric properties and to generate realistic ionospheric profiles. PROPLAB gives you the power to select either the URSI or CCIR models.

PROPLAB uses a corrected version of the most recent International Reference Ionosphere. The uncorrected code failed to properly model the F1 region under some conditions, resulting in a discontinuity in the electron density joining the F1-layer region with the lower-F2 layer.

The CCIR and URSI models both produce different results. The option to select one of these two models may improve the accuracy of some results. For most purposes, we recommend the URSI model, although under some conditions the CCIR model may prove to be more accurate. If one model fails to prove accurate enough for your purposes, try the other.

Consider the electron density profile given in Figure 2.0. This profile was produced using the URSI model of the International Reference Ionosphere in PROPLAB. The bottomside of the ionosphere (below the maximum in electron density) consists of five regions. The lowest region of significance is the D-layer where electron densities begin to rise, but are still confined to relatively low levels. The E-layer exists above the D-region where there is usually a small peak in electron density. This is also where sporadic-E would appear, as a sharp increase in electron density near the E-region peak. Above the E-layer exists a valley region which is small near noon, but deepens at low solar elevations and during the night. Above the valley is an intermediate region that bridges the gap between the valley and the F-layer. Depending on season, time of day, etc, there may or may not be an F1 region present. Detection of the F1-region is usually more difficult because of F2-region dominance.

PROPLAB will let you produce ionospheric electron density profiles for any region of the Earth and any level of geophysical activity.

2.6.4 Propagation Paths

Radio signals always try to travel the shortest distance between two points. On a sphere such as the Earth (which is a close enough approximation), the shortest distance between two points is known as the great-circle distance. You can determine the great-circle path between any two points on a globe by stretching a taught string between the two points. For east-west northern hemisphere points, you will notice that the string appears to form an arc that arcs toward the northern pole before reaching the destination. Likewise, an east-west great-circle path in the southern hemisphere travels toward the southern pole before arcing back toward the destination. On north-south paths, the great-circle lies on one of the longitude meridians. Longitudes are therefore great-circles because their planes cut through the center of the Earth. Latitude circles do not have planes which cut through the center of the Earth, and are therefore not great-circles.

Radio signals that are transmitted between two east-west middle-latitude long-distance points have a fairly good chance of passing through the auroral zone, particularly during stronger periods of geomagnetic activity when the auroral zones have expanded in area.

The ionosphere is capable of transmitting signals approximately 4,000 kilometers in a single hop. This is generally known as the maximum one-hop distance. For greater distances, multiple hops are usually required. However, radio signals frequently travel far beyond this one-hop distance during chordal-hop propagation or ducting. PROPLAB has the power to determine when and how to accomplish communications using these special types of radio propagation modes.

2.6.5 Determining Propagation Conditions

The determination of ionospheric propagation conditions between two points is not an easy task. Conditions can vary widely from minute to minute, hour to hour, and day to day, and location to location. Many propagation prediction programs use algorithms that are optimized to improve calculation speed. In the process, they sacrifice accuracy. Others fail to consider important parameters such as the location of the auroral zones, and thereby suffer fairly serious inaccuracies particularly on transpolar and high-latitude paths. Consideration of a wide host of variables is required in order to help secure accuracy and reliability. And even then, the often unpredictable behaviour of the ionosphere may make it difficult to obtain accurate results.

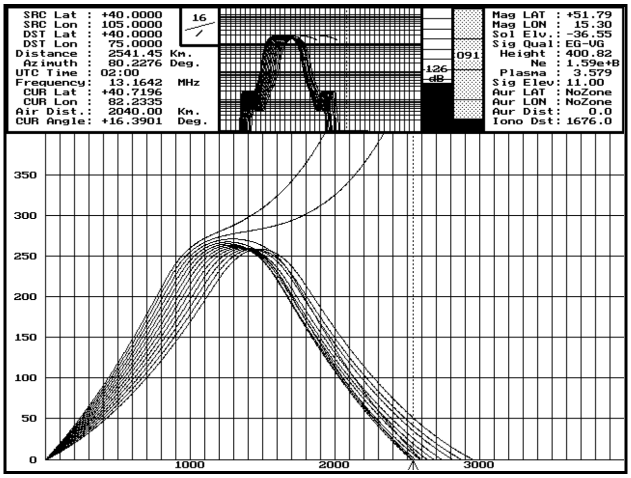
With PROPLAB, we decided to sacrifice speed in order to improve accuracy and reliability, which is what most radio communicators are after anyway. And when combined with the improved speed and processing power of the modern personal computer, even speed might not be a problem for many people running state-of-the-art computer systems.

Here is a small list of the more important parameters PROPLAB considers when determining propagation conditions:

* Entire path analyzed (no short-cuts).
* Reduction in electron density profiles due to geomagnetic activity.
* Passage through the auroral zone(s).
* Winter Anomaly.
* Passage through the polar region.
* Influence of Polar Cap Absorption.
* Equatorial Anomaly.
* Sunset/Sunrise Enhancement/Degradation modes.
* Influence of solar flares producing short wave fadeouts (SWFs).
* Geomagnetic activity.
* Sporadic-E.
* Solar zenith angle.
* D-region absorption.
* Auroral absorption.
* Date and Time.
* Frequency and transmission power.
* Possible radiowave inter-layer guiding modes.
* Sunspot dependencies.
* Varying ground-hop absorption.
* Signal multipathing.
* Signal spatial spreading loss.
* Ionospheric focusing and defocusing.
* Signal dependence on magnetic latitude.

Each of these items may be inter-related or dependent on each other in differing ways. Determination of signal quality must carefully take these (and other) parameters and their inter-relationships into consideration to produce results that can reflect the diverse conditions in the ionosphere.

2.6.6 Skip Distance and Maximum Usable Frequency



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SRC Lon  : 105.0000
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DST Lon  :  75.0000
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UTC Time : 02:00
Frequency:  13.1642  MHz
CUR Lat  : +40.7196
CUR Lon  :  82.2335
Air Dist.:  2040.00  Km.
CUR Angle: +16.3901  Deg.

Mag LAT  : +51.79
Mag LON  :  15.30
Sol Elv. : -36.55
Sig Qual : EG-VG
Height   : 400.82
Ne       : 1.59e+B
Plasma   :  3.579
Sig Elev : 11.00
Aur LAT  : NoZone
Aur LON  : NoZone
Aur Dist :    0.0
Iono Dst : 1676.0
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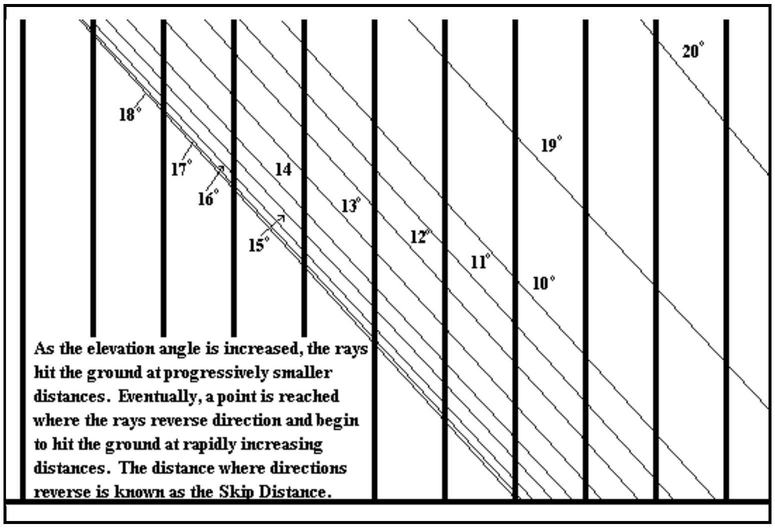
Figure 2.5: *MUF and Skip Distance*

When tracing rays through the ionosphere, it is useful to have an understanding of skip distances and maximum usable frequencies. Often, people confuse maximum usable frequencies with penetration (or critical) frequencies. For obliquely propagated radio waves, maximum usable frequencies are not equivalent to critical frequencies.

Consider Figure 2.5 in the following discussion. This figure shows a typical situation where, for a given frequency, the elevation angle is increased so that the signal eventually penetrates the ionosphere. Notice that as the elevation angle is increased, the distance between consecutive rays begins to decrease. Moreover, as the elevation increases, the ground-distance between the transmitter and the receiver decreases. If the elevation angle is further increased at regular increments, it can be seen in Figure 2.5 that a point is reached where the signal no longer hits the ground at decreasing distances, but rapidly increasing distances. The point where the distance changes direction (from decreasing to increasing) is known as the skip distance. It is interesting to note that another side-effect of this phenomenon is the increasing concentration of rays as the skip distance is approached. This effect is called ionospheric focusing and can result in significantly higher signal strengths than is normally possible.



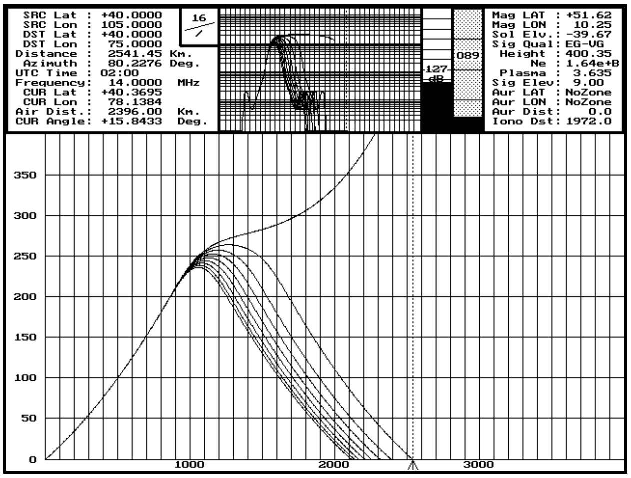
As the elevation angle is increased, the rays hit the ground at progressively smaller distances. Eventually, a point is reached where the rays reverse direction and begin to hit the ground at rapidly increasing distances. The distance where directions reverse is known as the Skip Distance.

Figure 2.6: *Illustration of Ionospheric Focusing*

Figure 2.6 shows a magnified view of the downgoing rays and a typical (if not somewhat exaggerated) example of ionospheric focusing. Each ray has been tagged with a number indicating the elevation angle used at the transmitter. It can be seen that as the elevation angle increases from 10 degrees to 18 degrees, the distance of each ray from the transmitter decreases. As well, the proximity of each ray to each other ray decreases, thereby increasing the concentration of signals per unit area. As the elevation angle of the rays is increased further, a point is reached where further increases in elevation cause the rays to increase in distance away from the transmitter, resulting in signal defocusing. These rays are called high-angle rays. High angle rays are inherently unstable, since very small changes in elevation angle can result in very large changes in propagated distances. For this reason, high-angle modes of propagation are usually unsuccessful or at the very least, unstable. Signals associated with high-angle modes are also usually fairly weak due to the defocusing which occurs. However, under some special conditions where the ionosphere is particularly stable, high-angle rays can result in communications at frequencies above the MUF.

Let's now go back to Figure 2.5. The maximum usable frequency in this example lies just outside of the skip distance, near the location where the arrow points at the bottom of the figure. MUFs occur in regions where ionospheric focusing is usually strongest.

In this example, it can be seen that the elevation angle that coincides with the maximum usable frequency does not coincide with the elevation angle corresponding to the penetration frequency. The penetration frequency is slightly higher than the maximum usable frequency.



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 SRC Lon  : 105.0000
 DST Lat  : +40.0000
 DST Lon  :  75.0000
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 Azimuth  :  80.2276 Deg.
UTC Time  : 02:00
Frequency:  14.0000  MHz
 CUR Lat  : +40.3695
 CUR Lon  :  78.1384
Air Dist.:  2396.00  Km.
CUR Angle: +15.8433  Deg.
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Mag LAT  : +51.62
Mag LON  :  10.25
Sol Elv.: -39.67
Sig Qual: EG-VG
 Height  : 400.35
      Ne  : 1.64e+B
 Plasma  :  3.635
Sig Elev:  9.00
Aur LAT  : NoZone
Aur LON  : NoZone
Aur Dist:    0.0
Iono Dst: 1972.0
```

Figure 2.7: *Frequency Sweep showing concept of MUF and penetration frequency*

To help solidify the meaning of maximum usable frequency, consider the final example given in Figure 2.7. The same parameters were used in this figure as those that were used to produce Figure 2.5, except that a fixed angle of elevation of 9 degrees is used while varying the frequency. The location denoted by the arrow at the bottom of both of these figures is the location of the MUF. In these examples, the MUF is approximately 13.2 MHz. Figure 2.7 sweeps the frequency from 10 MHz to 14 MHz in steps of 0.5 MHz (or 500 KHz), and shows that for an elevation angle of 9 degrees, the maximum usable frequency is approximately 13.0 MHz (corresponding to the ray that hits the ground where the arrow points). This frequency differs from the penetration frequency by about 1.0 MHz, for as Figure 2.7 illustrates, the penetration frequency occurs at about 14.0 MHz. The high-angle rays are those which would be reflected by the ionosphere between the MUF of 13 MHz and the penetration frequency of 14 MHz.

2.7 Ray Tracing Techniques

PROPLAB PRO Version 2.0 is equipped with *two* major ray-tracing techniques that compute how signals propagate into and through the ionosphere. These two methods will hereafter be called the *simple* and *comprehensive* (or *complex*) ray-tracing techniques.

The simple ray-tracing technique is faster than the comprehensive method, but is much less accurate. Nevertheless, it produces statistics which are of fundamental importance such as the distance the signals travel through the auroral zones, the behavior of signals as they interact with regions of sporadic-E, and much more. This method does *not* include effects of the Earth's magnetic field or the process of electron collisions with neutral particles in the atmosphere (a very important parameter for determining ionospheric absorption and accurate ray paths). However, it does estimate the effects of geomagnetic activity on radio signals.

The comprehensive ray-tracing method is a sophisticated and extremely powerful ray-tracing engine that should be used to accurately trace signals through the ionosphere. It *will*, if desired, include effects of the Earth's magnetic field and electron collisions with neutral particles. It will also optionally trace signals through a realistic three-dimensional ionosphere. However, in order to keep the program which is responsible for these sophisticated functions within the memory constraints imposed by the DOS environment, the rays must be traced through an undisturbed geomagnetic field. Therefore, the geomagnetic A-index is not used in the complex ray-tracing technique. However, the effects of geomagnetic activity can be approximated by inputting an *effective* sunspot number that is correlated with solar activity *and* geomagnetic activity. Similarly, due to memory constraints, the complex ray-tracing method cannot include effects of the auroral zones. These are the two most important parameters which the complex method does not include in its computations. However, the increased accuracy obtained by using the complex method outweighs the influence of the auroral zones and geomagnetic activity. Using the complex method, the influence of ionospheric tilts, chordal hop propagation, ducting and much more can be accurately displayed on-screen. These effects are *global* in nature and affect all signals travelling everywhere, unlike the effects of geomagnetic and auroral activity which tend to be localized more to the high and polar latitude regions.

Throughout this manual, references will be made to the *simple* or *complex* techniques. Many of the available options apply to only one of these techniques. Others apply to both. It is important to know which options apply to which techniques so that PROPLAB is appropriately set up.

SECTION 3 - PROPLAB

The file "README.NEW" which is installed with PROPLAB may contain information that is not contained in this manual. Consult that file for information not appearing in this manual.

3.1 Installation of PROPLAB

To install PROPLAB on your hard drive, insert the program code disk into drive A: and type: "A:INSTALL". After supplying any necessary information, PROPLAB will begin installing the software in the directory "C:\PROPLAB" on your hard drive. Part of the installation procedure includes generating maps centered on your particular geographical position. Each of these differing maps can be used by the PROPLAB software. In order for some of the functions of PROPLAB to operate properly, it is imperative that you install at least one map: a Plate Carree map must reside in your map library for these functions to work.

IMPORTANT: PROPLAB PRO Version 2.0 will now construct full-color global maps where the ocean is colored blue and the land is colored brown with large lakes also colored blue. This new enhancement provides aesthetically pleasing maps compared to the mono-color maps used in previous releases. If you do not want to use these new full-color maps but would rather stick with the older style maps, use the older map management utility on your disk named "MKMAPV1.EXE" to create the older-style map library. You can now also customize the colors of the maps (consult Section 3.2 of this manual for more information).

FOR INDIVIDUALS UPGRADING TO VERSION 2.0 If you have an old version of PROPLAB on your computer, you MUST DELETE EVERYTHING in the old PROPLAB directory before installing Version 2.0 of PROPLAB PRO. There are some significant changes to the way PROPLAB handles some of the files and utilities. In order for it to be properly installed, all old versions must be completely deleted from your hard-drive (unless you are installing PROPLAB PRO Version 2.0 in a different directory). This does NOT apply if you are installing PROPLAB PRO Version 2.0 in a directory that is completely separate from the old version. However, any DOS environment variables that refer to the old version must be modified to point to the new version after it has been successfully installed.

If you previously purchased our Professional Dynamic Auroral Oval Simulator, you will notice that the older mono-colored maps are used. However, the format of the map files are identical. Those who use our Auroral Oval Simulator can therefore see whether they want to use the full-color map databases by copying the "MAPS.LIB" file from the PROPLAB directory into the directory containing the Auroral Simulation Software.

After the installation procedure is complete, you can execute PROPLAB from your MSDOS command prompt. PROPLAB PRO has not been tested very extensively under Windows 95 (in a DOS mode). It does, however, work for the most part under Windows 3.1 in DOS mode. Keep in mind, however, that PROPLAB was developed for the DOS environment. It will probably be ported over to Windows 95 in later releases.

3.2 Running PROPLAB, Changing Colors, and Setting Up the Printer

There are three different ways to execute PROPLAB from the DOS command prompt. You may type "PROPLAB" and press ENTER, or you can type "PROPLAB -" and press ENTER. The first command loads and runs PROPLAB, permitting you to see the opening title page, etc. The second command loads PROPLAB, but skips displaying the title page and instead takes you directly to the main menu of PROPLAB. Use either of these two methods to run PROPLAB normally. However, the *first-time* you run PROPLAB, you should run it by typing "PROPLAB" and pressing ENTER. The first time PROPLAB is run, it gathers information about your current system configuration and writes this information to a file for future reference. After you have run PROPLAB once, you can select any of these three execution methods.

The third method of running PROPLAB permits you to change the colors (text and graphics) used in PROPLAB. To do this, type "PROPLAB SETCOLORS" and press ENTER. PROPLAB then asks you to type in the new colors to be used by PROPLAB.

The VGA graphics employed by PROPLAB PRO allow up to 16 different colors to be displayed at the same time. PROPLAB PRO Version 2.0 lets you change any of these colors to any ratio of RGB (Red Green Blue) values. It is therefore possible to change any of the colors used by PROPLAB's graphics plots to any shade or color desired. For example, an RGB combination of 0,0,0 (Red=0, Green=0, Blue=0) results in the color BLACK, since all three primary colors have an intensity of 0 (or dark). The maximum RGB value that can be input is 63, which represents a brilliant intensity. For example, an RGB value of 0,63,0 will produce the brightest GREEN color possible. A value of 0,32,0 will produce a GREEN color that is half as bright as the previous example. This will appear on-screen as a darker colored GREEN.

PROPLAB PRO asks you if you want to reset the RGB colors to their default values. If you have experimented with the RGB colors and need to reset the colors back to their originals, respond affirmatively to this prompt (which is only asked if you execute PROPLAB using the "PROPLAB SETCOLORS" command at the DOS prompt.

To change the graphics color BLACK (which is also the background color) to WHITE (so all graphics are drawn with a white background and black lettering), change the RGB values for the color BLACK from 0,0,0 to 63,63,63. Similarly, change the RGB values for the color WHITE from 63,63,63 to 0,0,0. To make the color RED a dark green, you might change the RGB values for the color RED from 63,0,0 to 0,25,0. Almost any other color can be created by using varying ratios of Red to Green to Blue. For example, you could change the color of YELLOW to a custom color using an example RGB value combination of: 14,48,36.

The changes you make to the colors of PROPLAB are reflected in all of the modules of PROPLAB, *including* the Map Management System (MAKEMAP.EXE). So, if you want to recreate your map database using different map colors, you simply need to execute PROPLAB via "PROPLAB SETCOLORS" and then change the RGB values of the appropriate map colors. For example, to make the oceans a GRAY color instead of blue, you would change the RGB value for the color BLUE to an RGB combination such as 40,40,40. Then rerun the MAKEMAP.EXE utility to reconstruct the desired maps using the new color. ***Keep in mind* that the all other PROPLAB modules that use the color BLUE will now use the color of GRAY instead. So the colors you change may have side-effects with the colors used in other sections of PROPLAB.**

Some of the subprograms within PROPLAB are large. For this reason, the PROPLAB.EXE program basically controls the main functions of PROPLAB, sets up the relevant parameters, contains the main menu and submenus, and redirects control to the other subprograms when appropriate.

Most of the functions in PROPLAB are computation-intensive and require at least a 386 computer to operate at a decent speed. However, even some 386-based systems (ex. those without math coprocessors) may operate relatively slowly while using this software. For this reason, systems equipped with math coprocessors or 486-or-better based computers are much better equipped to handle the large quantity of complex floating-point calculations required for many of the functions of this package. Use of coprocessors will significantly speed up operations and are recommended for use with this software. PROPLAB will operate fine if you don't have a math coprocessor in your system. It will simply take more time to complete some of the functions.

We have made every effort to test this software for bugs. Although we can't promise that all of the bugs have been corrected, we hope they have. If you find a bug in the software, we would appreciate it if you would write to us and notify us of the problem. Inform us of the type of computer system you have, hardware configuration, type and version of the disk operating system you are using, as well as any other pertinent information that will help us locate any potential problems in the system. We will do our best to correct any problems that are found as quickly as possible. Alternatively, send bug reports to us on the Internet via: Oler@Solar.Uleth.CA or COler@Solar.Stanford.Edu.

PROPLAB will print graphic-screens directly to your dot-matrix printer. But before this can be accomplished, PROPLAB's printer control file "PROPLAB.PTR" must be modified to work with your particular printer. All of the instructions necessary to alter this file are contained in that file. Edit it with a standard word processor or text editor to meet your printers requirements. This printer control file is only intended for dot-matrix printers. If you have a laser-printer (PostScript), you should be using the command to create a PostScript image file. Do this by pressing "P" at any of the graphics screens presented by PROPLAB. Then exit to DOS and send the saved PostScript file (which contains the extension .PS) to your printer.

At any of the graphic-screens presented by PROPLAB (except the Broadcast Coverage Map screens), pressing "H" (short for Hard copy) will cause PROPLAB to begin sending the contents of the current graphic screen to your dot-matrix printer.

If you fail to modify the printer control file "PROPLAB.PTR" correctly for your printer, you may see garbage printed instead of an accurate rendition of the graphic display. The initialization strings are of greatest importance. Make certain that the initialization strings contain (if needed by your printer) the correct size of the printed lines and that the given size matches the "LOCKSIZE" parameter (read the file "PROPLAB.PTR" for more information). Failure to do this will cause improper printer operation. Those with laser-printers may find it easier to simply convert the graphic screens to a PostScript compatible format by pressing "P" (Postscript) at any of the graphic screens. This is the only way to reproduce the broadcast-coverage map screens which are heavily color-coordinated.

Consult your printer manual for all of the initialization string codes which should be used in the printer control file. Each printer usually differs, which is one reason why a printer control file is used. It permits essentially universal compatibility with printers.

If you have a laser-printer, don't use the "H" command as this is optimized only for dot-matrix printers. For later printers, create a "P"ostScript version of the graphic screen. After it has been saved to a PostScript file (containing the extension ".PS"), exit to DOS and copy the PostScript file to your laser printer.

3.3 Setting the Required Parameters

The eighth choice of the main menu is an Options Menu. This is where you setup most of the parameters required to run PROPLAB. It is where you define the operating frequency, transmitter power, date and time, location of the transmitter and receiver, sunspot number, etc. The options in this section should be adjusted to fit your specifications before you perform any of the major functions of PROPLAB, such as ray-tracing or determining MUFs, etc. Here, we will briefly describe the available options.

3.3.1 Setting the Transmitter/Receiver Locations and Time Zones

PROPLAB requires the geographical position of the transmitter and receiver in order to work. The first two options of the Options Menu let you change these parameters to fit your needs.

Geographical positions should be entered in decimal notation (not in degrees, minutes, and seconds notation). That is, if your geographical location is 50 degrees north latitude, 30 minutes and 45 seconds, you would enter your geographical position as 50.5125 - not as 50.3045. In addition, all latitudes north of the equator must be entered as positive numbers, while those latitudes south of the equator should be entered as negative numbers.

Geographical longitude values can be measured in decimal degrees west or east of Greenwich. For example, Denver Colorado is located at approximately 105 degrees west longitude and would therefore be entered in PROPLAB at a position of 105 degrees. Again, decimal values must be used, not degrees minutes and seconds. Sydney Australia is located at 150 degrees east longitude or 210 degrees west longitude. If measurements are given in degrees east of Greenwich, negative values must be used. That is, if Sydney's eastern longitude value were entered in PROPLAB, the value -150 would be used.

PROPLAB requires knowledge of the time zone of the transmitter so that if local time is used, PROPLAB can compute what the local time is at the receiver. PROPLAB has the ability to automatically guestimate the time zone of the transmitter by dividing the geographical longitude of the transmitter by 15 degrees (since the Sun travels 15 degrees of longitude per hour). Although this is usually accurate enough, some regions may not be in easily divisible time-zones. PROPLAB therefore gives you the option of having the computer automatically calculate the time zone for you, or allowing you to input the time zone manually. If you choose the latter, time zone information must be entered as a positive or negative integer reflecting the time-difference between Universal time (UTC) and local time for the current transmitter geographical location. Positive integers are used for locations that are west of Greenwich. Negative integers are used for locations that are east of Greenwich. For example, Denver Colorado is west of Greenwich and therefore uses a positive integer value of +7 hours, since the difference between local time and Universal time is 7 hours. Similarly, Sydney would use a value of about -10 hours. During daylight savings time, it may be necessary to include the adjustment in this time-zone input.

When PROPLAB is configured to automatically compute the time zone information, the acronym "AutoZone" is set to ON. The status of this "AutoZone" variable can be determined at the main Options Menu. If it is set to OFF, manual input of time-zone information is required each time the transmitter location is changed.

PROPLAB permits the selection of geographical locations by one of three different methods: by numerical entry, name entry, or grid-coordinate entry. Numerical entries are those where the actual latitudes and longitudes are typed. PROPLAB will also search through a geographical dictionary of locations (city names or other aliases) and accept matching entries, _if_ you have enabled the AutoQTH function. For example, if the geographical dictionary contains "Orlando"'s geographical coordinates, you can inform PROPLAB to automatically grab Orlando's coordinates from the geographical dictionary by simply typing "Orlando" or "orlando" or "ORLANDO" or "oRLaNDo" at any of the prompts requesting the "Latitude or Site Name". The names are case-insensitive.

The geographical dictionary is located in the file "PROPLAB.LOC". This is a simple text file that can be edited with a standard text editor or word processor. Lines prepended with an asterisk "*" are treated as comments. Each line of this file must follow this format:

CITY NAME=LATITUDE,LONGITUDE,TIME-ZONE

For example, "Philadelphia=40.0,75.0,-5" is a valid entry defining the approximate location of Philadelphia. At any of PROPLAB's prompts requesting a Latitude or Site Name, you could type "Philadelphia" and PROPLAB would automatically enter the latitude and longitude values as 40.0 and 75.0 respectively. The "-5" defines what time-zone Philadelphia is located in. In this case, Philadelphia is -5 hours different than Universal Time, or the time reckoned from Greenwich England. Mountain Standard Time is "-7" hours. Pacific Standard Time is "-8" hours, etc.

The third method of entering in locations is using the grid-location method. This method is popular amongst people who frequent the VHF and UHF bands. This method divides the Earth into hundreds of small 2-degree-wide squares. Each square is given a special fixed name or designation such as "DN43ah". To use grid-square designations at the prompts requesting Latitudes or Site Names, simply prepend the grid-square name with an exclamation mark "!". For example, "!DN43ah". PROPLAB will then automatically convert this grid-square name into the appropriate geographical latitude and longitude coordinates.

3.3.2 Graphically Setup Transmitter/Receiver Locations

If your system is equipped with a mouse, you can graphically set the position of the transmitter and receiver using the third option of the Main Menu in PROPLAB, "Setup Sporadic-E / Xmit-Recvr Locations". To use this feature, a Plate Carree map projection must exist in the map library. If the map exists, it is displayed on-screen along with the location of the mouse cursor, the location of the auroral zones, the location of the sunrise/sunset terminator (or grayline), and the location where the Sun appears directly overhead. PROPLAB PRO also lets you plot an additional line that marks the regions of the world where the sun is a specific number of degrees above or below the horizon. For example, you can now instantly determine the regions of the world where evening and morning twilight is beginning or ending by telling PROPLAB to plot a line which marks the locations where the sun is, say, 12 degrees below the horizon. This is accomplished by specifying a value of -12 as the angle for the sun. Negative values represent angles below the horizon. Positive values represent angles of the sun above the horizon. A value of zero then, represents the locations around the world where the sun is exactly setting (or crossing the horizon). This is an extremely powerful function that lets you visually determine precisely the proximity of your chosen radio path to the various zones of influence.

PROPLAB PRO Version 2.0 is now equipped with another major function which will let you plot these various zones of influence in *real-time*! Consult the appropriate section of this manual dealing with the real-time mapping system.

To set a new transmitter/receiver location pair, move the mouse cursor to the position of the transmitter and click on the left mouse button to mark that location. Then, move the mouse to the location of the receiver and click on the right mouse button. The great-circle path between the two points will then be traced on-screen along with updated positions of the auroral ovals, the grayline, and the Sun if local time is being used.

You can alternatively keep the location of the transmitter constant and change the position of the receiver by moving the mouse to the new location of the receiver and clicking on the right mouse button. This will only change the position of the receiver and will leave the transmitter location constant.

This powerful feature of PROPLAB permits you to instantly determine what signal paths might cross into the influential auroral zones, or what signal paths to use along the grayline, etc. The usefulness of this feature goes far beyond the simple establishment of transmitter and receiver locations. As you become more skilled in this use of this software, you will discover the greater importance of these other included features.

You can save copies of these screen images to disk in one of several formats. By pressing "G", you can save the screen to a GIF image file. By pressing the "P" key, you can save the screen image to a PostScript-compatible file for sending to a laser-printer. And by pressing "S", you can save the screen image to a special format that can later be used by PROPLAB to superimpose other information on. For example, you could superimpose contours of maximum usable frequencies on the map used to select transmitter and receiver locations. The additional information included on these maps (location of the auroral zones, location of sporadic-E, the traced path between the transmitter and receiver, grayline, etc) would provide a wealth of indispensable information when combined with contours of ionospheric properties. See Section 4 for more information regarding these features.

3.3.3 Ray Tracing Speed, Path Type, and Termination Mode

When performing ray-tracing functions in PROPLAB using the *simple technique*, you can set the speed with which PROPLAB traces rays by using the third option of the Options Menu. This value is preset to 10, which is a nice round arbitrary figure that provides decent speed of operation and accuracy for systems that are both equipped with and without math coprocessors.

Lower values cause PROPLAB to trace rays through the ionosphere in smaller increments. This may increase the accuracy of the results slightly, but will also slow down the speed of operation by increasing the number of required calculations. Likewise, larger values will speed up traced rays by tracing through the ionosphere in larger steps. However, the results will become less accurate as larger ray tracing speed values are used. This is particularly true for signals that must pass through regions of sporadic-E, where density increases rapidly over a short height interval. A judicious choice of ray tracing speed is required when considering the effects of sporadic-E on traced rays. If a value too large is used, the signal may completely step over the region containing sporadic-E. For this reason, smaller values of around (or less than) 10 are recommended when taking sporadic-E into consideration.

You can also define the type of path you want traced from within this option. This only applies to the *simple* ray-tracing technique. To use Long Paths, select "L". To use Short Paths, select "S". The *complex* ray-tracing method cannot trace rays using long-paths. It always traces rays using the shortest distance between the transmitter and the receiver. It can therefore only trace rays out to a distance of 20,000 kilometers, which is the circumference of half of the Earth and is the greatest short-path distance between two points.

The Termination Mode applies to *both* of the available ray-tracing techniques and tells PROPLAB when you want it to stop tracing rays through the ionosphere. If the signal strength or quality becomes degraded to the point where it is useless or "blacked-out", a white "X" is stamped on-screen at the point where the signal vanishes (the X is only displayed when using the *simple* method). PROPLAB will normally continue tracing the ray through the ionosphere even though the signal quality or strength is at the blackout condition. If you want PROPLAB to stop tracing rays whenever the blackout condition is reached, you can change the termination mode to stop ray-tracing if this occurs. For the *complex* ray-tracing technique, this occurs when the signal strength reaches zero decibels (dB). This will help speed up ray-tracing sessions by ignoring signals that lose all power.

3.3.4 Choosing Ionospheric Models (URSI or CCIR)

PROPLAB is integrated with two different ionospheric models while using the *simple* ray-tracing technique and *six* ionospheric models while using the *complex* ray-tracing technique. These models are discussed below.

Ionospheric models are necessary in order to describe the characteristics of the ionosphere around the world. These models effectively describe the electron density of the ionosphere for any location around the world and level of solar activity. They are of critical importance to PROPLAB, because it is the density of electrons in the ionosphere that is responsible for the refraction (and reflection) of radio signals through the ionosphere.

3.3.4.1 Models to use with the Simple Ray-Tracing Technique

The two available models that can be used with the simple ray-tracing technique are known as the URSI and CCIR models. Both models are accurate and reliable and are proven performers and produce similar results. There is no real preference of one over the other. The choice of which model to use is up to you. The default has been arbitrarily set to the URSI model.

3.3.4.2 Models to use with the Complex Ray-Tracing Technique

The complex ray-tracing technique is able to use one of up to six different ionospheric models, described as either ***two-dimensional*** or ***three-dimensional*** as follows. You can select which model to use from Main Menu Option #8, Suboption #18, Choice #4.

Model #1: URSI Two-Dimensional Model

This model is based on the URSI ionospheric model and describes the ionospheric characteristics for a given point on the Earth up to an altitude of 1,000 kilometers. It does *not* describe ionospheric characteristics in three-dimensions and therefore should only be used when performing comprehensive *single-hop* ray-tracing plots. The two-dimensional comprehensive ray-tracing technique can only reliably handle single-hops because only one two-dimensional ionospheric profile is generated. On subsequent hops using the two-dimensional model, the same ionospheric profile is used which represents the characteristics of the ionosphere at the midpoint of the first hop. Subsequent hops therefore use the same ionospheric profile which differs from reality. For multi-hop paths, use one of the three-dimensional models below.

Model #2: URSI Three-Dimensional Model

This model is based on the URSI ionospheric model and describes the ionospheric characteristics in *three* dimensions up to 1,000 kilometers in height. This model (or another three-dimensional model) should be used when accuracy is important, when chordal hop propagation or ducting is to be analyzed, or when there may be more than one ground reflection on the way to the receiver.

Model #3: CCIR Two-Dimensional Model

This model is based on the CCIR ionospheric model and has the same limitations as those that describe Model #1. Use the CCIR Three-Dimensional Model for multi-hop paths, chordal hop paths, ducting, etc.

Model #4: CCIR Three-Dimensional Model

This model is the three-dimensional version of the CCIR ionospheric model and is identical to Model #2, except it uses the CCIR method of computing ionospheric characteristics.

Model #5: Quasi-Parabolic Two-Dimensional Model

This model is very similar to the ionospheric profile models employed by other simpler propagation programs. It uses a standard parabolic equation to describe the electron density throughout the ionosphere. Use of this model demands a fair bit of knowledge of ionospheric electron density shapes and a familiarity with the standard parabolic profile equations. Before this model can be used to produce an ionosphere in which rays can be traced, several options must be defined in the comprehensive ray-tracing options menu (Main Menu #8, Sub option #18). In particular, you must define the critical frequency of the F2 layer at the mid point of the path (if this is unknown, you can use the CCIR or URSI model with PROPLAB to print out the predicted critical F2-layer frequency (use Main Menu Option #7 after defining the location of the transmitter and receiver)). You must also specify the thickness of the F2-layer and the height where the electron density reaches a maximum in the ionosphere. These parameters will be discussed in greater detail in the section which deals with these settable options. This model is only valid for single-hop paths.

Model #6: Alpha-Chapman Two-Dimensional Model

This model is similar to Model #5 and requires the same type of information. It is also only valid for single-hop paths.

3.3.4.3 The "Right" Model to Use

There is no "right" or "wrong" ionospheric model. The model you use will usually be dictated by exactly what you require. However, if you are not sure what you need or which model you should select, use one of the three-dimensional models. They tend to be a little more time-consuming to set up but are not as prone to produce confusing results. More importantly, the results they produce are more accurate and easier to interpret.

Generally, for most applications, either the URSI or CCIR three-dimensional models will be of greatest value. The two-dimensional models should only be used if you are tracing signals through the ionosphere that you know will never need to be traced beyond one hop. That is, the signals should never be reflected by the ground and back into the ionosphere before reaching or nearing the reception point. Paths beyond 4,000 kilometers definitely should not use the two-dimensional models. Instead, one of the three-dimensional models should be used.

Models #5 and #6 are oriented more towards professionals who know the capabilities and uses for Quasi-Parabolic and Alpha-Chapman electron density equations. If you are not familiar with these models, selecting them may prove to be problematic and produce unrealistic results.

In other words, if ever in doubt, use either the URSI or CCIR three-dimensional models. They will automatically handle all of the things which the two-dimensional models do not, such as recomputing electron density profiles at each point along the traced ray, etc.

3.3.5 Setting the Operating Frequency

The fifth option of PROPLABs Options Menu applies to both the *simple* and the *complex* ray-tracing techniques. It lets you define the operating frequency of the transmitter (in MHz). This is a very critical parameter. PROPLAB could not function without it, for obvious reasons.

The operating frequency must be entered in units of megahertz (MHz). For example, a transmitter that is set up to operate on the 40 meter shortwave band would use a frequency of between approximately 7.0 and 7.3 MHz.

There are no real limits applied to the operating frequency. Frequencies in the Medium Frequency bands or frequencies in the VHF bands can be input. However, please note that frequencies below about 2 MHz may produce increasingly error-prone results with the *simple* ray-tracing method. The *complex* method is better able to accurately handle these wide ranges in frequencies since they use equations which accurately model the physical properties and behavior of signals of almost any frequency.

3.3.6 Setting the Date/Time and Auto-Sunspot-Number Computation

This option applies to *both* of the ray-tracing methods.

The sixth option of the Options Menu permits you to define the date and time. Enter the date in the format YY,MM,DD and the time in the format HHMM. For example, 08 December 1993 at 4:30 pm would be entered (using local time) as: 93,12,08 for the date, and 1630 for the time. Be sure to enter the time according to how you have setup PROPLAB. If local time is used, use local time. If UTC time is used, use Universal time.

This option also allows you to enable or disable the automatic computation of the sunspot number if you also are using the BCAST Solar and Geophysical Database Management Software. If you are not using this software, this feature should be disabled to permit manual entry of the sunspot number. If you have the BCAST software installed and enter a date which is in the BCAST database, PROPLAB will automatically attempt to compute the 12-month mean sunspot number from the BCAST database (for median results, the 12-month mean sunspot number is recommended). It will also extract the geomagnetic A-index for the given date from the BCAST records and automatically modify these parameters for the new date chosen.

If you want to maintain full control over what values are input, disable this auto-computation feature and enter in the data manually. If this feature is enabled, you will notice a time-lag while the system tries to retrieve the necessary data from the BCAST database. If PROPLAB cannot locate the BCAST database, it will abort without any changes. The DOS environment variable "BCAST" should point to the directory containing the database.

3.3.7 Setting the Transmitter Power

This option applies to *both* of the ray-tracing techniques.

NOTICE: Previous versions of PROPLAB required the input of a "relative transmitter power" figure. PROPLAB PRO Version 2.0 no longer asks for this. It instead requires the *actual* power of the transmitter in Watts. For example, a 10 kilowatt transmitter would be entered as 10000.

This function of the Options Menu lets you set the transmitter power (in watts). It is used by both the simple and the comprehensive ray-tracing techniques to compute the signal strength of the ray being traced.

The simple ray-tracing technique produces signal strength results that are not rigorously computed, but they do contain estimated effects of auroral absorption and other anomalies that can affect signals.

The comprehensive ray-tracing method rigorously computes signal strength values based on actual computed ionospheric absorption values, signal spreading loss, etc. The comprehensive technique will produce results that are more closely aligned with reality than the simple method (except perhaps during geomagnetic storms, as geomagnetic activity and auroral activity are not taken into consideration with the comprehensive technique, as discussed earlier).

3.3.8 Setting Ranges and Steps

This option applies to *both* ray-tracing techniques.

PROPLAB often requires a range of values or step values to use in performing certain functions. For example, when ray tracing signals from one point to another using elevation angles of between 0 and 20 degrees, these values would be modified to cover the range and step values needed to complete the tracings.

In most instances, you will not need to use this choice of the Options Menu. The software will automatically prompt you for the appropriate ranges and steps.

3.3.9 Selecting Local or Universal Time

This option applies to *both* ray-tracing techniques.

Using this choice of the Options Menu, you are able to change the type of time used in PROPLAB. Local time is the time you set your alarm clock to when waking up in the morning. Universal time is reckoned from Greenwich England. It is the time on which all other times around the world are based. Universal time is the same for everyone, everywhere. Universal time can be determined anytime of the day, to the second, by listening to radio stations WWV and WWVH on the shortwave frequencies 2.5, 5.0, 10, 15, and 20 MHz. There are other equally accurate clocks on the broadcast bands, but those mentioned above are the most accessible.

Select whichever type of time you need to use. If you use local time, PROPLAB will convert it when necessary to equivalent Universal Time using the Time Zone information described earlier. All dates and times entered into PROPLAB will be reckoned according to the type of time selected here.

3.3.10 Setting the Geomagnetic A-Index

This option is only used by the *simple* ray-tracing method and several of the supporting PROPLAB functions, such as the real-time mapping system.

The geomagnetic A-index describes how active the geomagnetic field is at a given time. The value which should be used here can be found by listening to radio stations WWV or WWVH at 18 minutes past each hour on the frequencies 2.5, 5, 10, 15, or 20 MHz. In some instances, it may be useful to convert the given K-index value (which is measured every 3 hours) to an associated A-index value. This can be done using the table of K/A Indices given in Section 2.3.1 (The Geomagnetic K-Index). For example, since a middle-latitude K-index of 5 is associated with an a_k index of 48, the A-index for that 3-hour interval would be 48. Using K-indices in this manner to help compute shorter-term A-indices may (or may not) result in better short-term determination of propagation conditions. Success using this technique may vary from one event to another.

Overall, PROPLAB is optimized to use the 24-hour A-index value given by WWV and WWVH. Quiet geomagnetic and ionospheric conditions are assumed to exist with A-indices between about 5 and 10. Input values of 5 can also be used to produce monthly median results. For example, to create monthly median maps of critical frequencies or Maximum Usable Frequencies, an A-index value of 5 or lower should be used. Use of higher A-indices may give results that are not median in nature.

A "median" value is one which occurs 50% of the time.

3.3.11 Setting the Sunspot Number or Solar Flux

This option is used by *both* of the ray-tracing techniques.

PROPLAB permits the entry of either the sunspot number or the 10.7 cm (2800 MHz) solar radio flux. This information is used to help determine the strength (and intensity of ionization) of the ionosphere.

To input the sunspot number, simply type in the number at the prompt. To input the 10.7

cm solar radio flux value, prepend an "F" (for Flux) to the number you type. An upper or lower case F will work. For example, to input a sunspot number of 60, type "60" at the prompt. To input a solar flux value of 145 type "F145" or "f145".

If you enter a solar flux value, PROPLAB immediately converts that value to an equivalent sunspot number. That sunspot number is then used in all PROPLAB calculations.

You can obtain the 10.7 cm solar radio flux value from radio stations WWV or WWVH at 18 minutes past each hour on one of the frequencies: 2.5, 5, 10, 15, or 20 MHz. For greater accuracy, it is usually wise to enter the average sunspot number or solar flux values for the last week or more. The ionosphere reacts more slowly to changes in solar radiation. Average values are therefore usually more reliable than daily values.

For monthly median results, the 12-month mean sunspot number or 12-month mean solar flux value must be given. If you are using the BCAST software and have enabled the Auto-SSN-Calculation feature, PROPLAB will automatically search the BCAST database for the given date and compute the 12-month mean sunspot number for you (when you change dates).

3.3.12 Selecting the Number of Allowed Hops

This option is used by *both* of the ray-tracing techniques.

When ray-tracing signals between two distant points, it may be necessary for the ionospherically reflected signal to make more than one ground-hop to reach the destination. This option lets you define exactly how many hops are permitted when ray-tracing signals. If you hit ENTER at this prompt, PROPLAB will automatically permit as many ground-reflection as necessary for the signal to reach the destination. Once the destination has been reached (or surpassed), no more ground-hops are permitted. If you enter a value at this prompt, that value will be used as the maximum number of allowed hops. As soon as the number of hops reaches this value, tracing for that particular ray stops.

3.3.13 Selecting PROPLAB's Quick or Normal Modes

This option is only valid when using the *simple* ray-tracing method.

When tracing signals through the ionosphere using the Normal Mode, the upper information panel is continually updated as the signal is traced from the transmitter to the receiver. When the software is running in the Quick Mode, the upper information panel is not updated. Only the simultaneous electron density curve is updated in this mode. This has two major effects: it reduces the number of calculations and time-consuming screen-updates, and it significantly speeds up the tracing of the rays without sacrificing accuracy. One major disadvantage of using the Quick Mode is the loss of the computation of signal quality. Functions that rely on signal quality data, such as the generation of Broadcast Coverage Signal Quality Maps, will not work properly if the traced signals are done using this Quick Mode function.

For greater speed when using the Quick Mode, it is necessary to increase the ray tracing speed of the software (see Section 3.3.3).

3.3.14 Selecting Plane or Spherical Grids

This option is only available while using the *simple* ray-tracing technique.

PROPLAB uses a spherical ray-tracing algorithm regardless of the type of grid that is displayed. The examples given in this manual are of the plane-grid type. That is, the surface of the Earth is treated as a flat surface. Likewise, the ionosphere is displayed as a flat ionosphere, even though the algorithms still use a spherical Earth and a spherical ionosphere.

This choice of the Options Menu lets you change the type of surface you see. In the Plane Grid mode, you are given a flat surface. In the Spherical Grid mode, you are given a spherical surface and a spherical ionosphere to view the traced rays.

It must be stressed that even if you use the Plane Grid mode, all traced rays use spherical algorithms. This is why, when using the Plane Grid mode, traced rays are gradually bent upward as the distance away from the transmitter increases.

3.3.15 Selecting Grid Distances and Height Scales

This option only applies to rays that are traced using the *simple* method.

Use this option to define what distances should be displayed on-screen when tracing rays through the ionosphere. All distances, whether ground distances or height distances, must be in kilometers. For example, inputting a "Grid Distance" (or Ground distance) of 4000 km and a "Grid Height" of 400 km would, when tracing rays, display a grid 4000 km wide by 400 km high.

It is important to realize that the grid-distance should be at least as large as the distance between the transmitter and receiver. If the given grid distance is too small, traced rays will never reach the receiver but will be forced to stop when they reach the edge of the grid boundaries. For example, if the distance between the transmitter and receiver is 7000 km and you specify a grid distance of only 6500 km, the rays will hit the edge of the grid at 6500 km and will never reach the receiver 500 km beyond the end of the grid. To rectify this situation, a grid distance of at least 7000 km should be used.

3.3.16 Accounting for Solar Flares

This option is only valid for rays traced using the *simple* method.

The existence of solar flares during the time when signals are propagating through the ionosphere can have a significant impact on the quality of signals. Solar flares can result in strong absorption of signals in the lower ionosphere, particularly below the E layer.

PROPLAB lets you input the magnitude of a flare that may be influencing propagation at the given date and time. The value you enter must be a valid flare-magnitude as was described previously in the "Flare Rating System" (see section 2.2.3). For example, a magnitude M6.3 flare would be entered as "M6.3". A magnitude X4.2 flare would be entered as "X4.2". PROPLAB will not recognize flares in the A, B, or C-class range, since flares of these types are usually (if not always) incapable of producing any HF signal degradation.

Flares typically do not begin influencing propagation until they reach a class M1.0 level. Also, it is worth noting that flares do not have significant impacts on the dark-side of the Earth. Only sunlit regions of the ionosphere are affected. As a general rule, the higher the Sun is in the sky, the stronger the ionospheric impact will be from the associated flare x-rays.

Listen to radio stations WWV or WWVH for information regarding the state of the Sun at 18 minutes past each hour on 2.5, 5, 10, 15, and 20 MHz. Flares capable of influencing ionospheric radio communications exist when the recording states that solar activity was "moderate", "high", or "very high". "Low" and "very low" levels of solar activity denote 24-hour periods of time where no flares of significance occurred. Radio stations WWV and WWVH usually will not state the magnitude of observed flares. To find out this information, you must either call the duty forecaster at the Space Environment Services Center at 303-497-3171 (collect calls are not accepted), call the Solar Terrestrial Dispatch BBS at: 403-756-3008. If you have access to the electronic Internet network, you can obtain this information in near-real-time (maximum 3-hour real-time lag) by using the finger command: "finger solar@solar.uleth.ca" or by anonymously FTPing to the machine: "solar.uleth.ca" and grabbing the file "indices.doc" from the directory "pub/solar/Indices". A World Wide Web page will also become available very shortly (and may already be in operation). Contact: COler@Solar.Stanford.Edu to find out what this address is.

3.3.17 Defining Polar Cap Absorption and Screen Saving Functions

The Polar Cap Absorption section of this option only applies to the *simple* ray-tracing technique. The Screen Saving Functions apply to *both* the simple and the complex techniques.

The last choice of the Options menu gives you the ability to define the magnitude (or existence) of Polar Cap Absorption (or PCA) at the given date and time. PCA can have devastating impacts on transpolar and transauroral circuits.

PCA measurements can be entered directly into PROPLAB in units of decibels (dB) absorption. At the PCA input prompt, press ENTER if no absorption exists.

The existence of PCA can be determined by listening to radio stations WWV and WWVH at 18 minutes past each hour on 2.5, 5, 10, 15, and 20 MHz. Although they don't report the magnitude of PCA present, magnitude information can again be obtained from the same sources as given previously in section 3.3.16. Refer to that section for more information on the available sources.

This choice of the Options menu also lets you alter the way PROPLAB saves graphic screen images to disk. Results of ray-tracing analysis or other graphical screen products can be saved to disk by pressing the "G" or "P" keys. Pressing "G" causes PROPLAB to save the existing screen image to a GIF image file. Pressing "P" forces PROPLAB to save screen images to a PostScript-compatible file.

This option lets you alter the way screen images are saved. Screens can be saved to disk in a full-color mode or a black-and-white mode. The full-color mode saves screens to disk in full-color, as they appear on your screen. The black-and-white mode saves screen images to disk by first converting all non-black pixels to white and leaving black pixels black. The resulting screen is black and white and may work better if being printed on monotone printers.

3.3.18 Other Comprehensive Ray-Tracing Options

This option presents you with another full screen of modifiable ray-tracing parameters that deal exclusively with the comprehensive ray-tracing technique. These options are discussed in the following group of subsections.

3.3.18.1 Ray-Tracing Model / Ray Type

This option lets you change the type of ray-tracing model that should be used when performing comprehensive ray-tracings through the ionosphere. There are *five* models available. Four of these five models are based on formulas and techniques developed by Appleton and Hartree and are hence known as the Appleton-Hartree models. The fifth model is the Sen-Wyller model. This model produces similar results but obtains them in a different manner.

The first two Appleton-Hartree models *include* effects of the Earth's magnetic field (which therefore allows both ordinary and extraordinary rays to be traced). However, they differ in that the second model does *not* include the effects of electron collisions with neutral particles (a significant phenomenon that is directly responsible for a producing most of the observed ionospheric absorption).

The second and third models are similar to the first two, except *neither* of these two models include effects of the Earth's magnetic field. Only ordinary rays can therefore be traced using these two models. They differ in that the third model *does* include effects of electron collisions with neutral particles whereas the fourth model does not.

The fifth model computes the refractive indices and associated gradients using a different method than the Appleton-Hartree models, but produces similar results. It will likely only be of interest to those with a knowledge of the differences between the Appleton-Hartree and Sen-Wyller methods. This model does *not* include effects of the Earth's magnetic field but it does include the effects of electron collisions with neutral particles.

The default and recommended model is the Appleton-Hartree formula that *includes* effects of *both* the Earth's magnetic field *and* electron collisions with neutral particles (Model #1). This model will produce the most accurate ray-tracings. It will be slower than the others due to the increased number of complex computations that must be performed, but the ability to trace extraordinary rays as well as the added accuracy of the tracings is more important than the increased computation time.

3.3.18.2 Magnetic Field Model

This option lets you define the type of model to use to describe the Earth's magnetic field. Several models are supported, but only one will likely be used for those with serious applications.

The first choice of this suboption specifies that *no magnetic field* should be used. If this option is selected, the type of ray-tracing model selected (see Section 3.3.18.1) should correspond to a model that does not require a magnetic field.

The second choice is the default and recommended choice for those who are concerned about accuracy. This choice selects a standard dipole field model. This model closely resembles the actual shape and intensity of the Earth's magnetic field and will produce the best results for most applications.

The third choice selects a model that assumes the DIP angle of the magnetic field is constant. The gyrofrequency of this model also increases as the cube of the distance. This model *will* produce unrealistic results unless the user is familiar with appropriate applications for this model.

The fourth choice selects a model that assumes a *constant* DIP angle *and* a constant gyrofrequency, regardless of the location of the traced rays. Again, this model *will* produce inaccurate and unrealistic results unless the user is familiar with the appropriate applications for this model.

We recommend using the second choice to select the *Dipole Field Model* . For general applications, this will produce the best and most reliable results.

3.3.18.3 Collision Frequency Model

This subsection defines the type of model that should be used to represent the electron collision frequency through the Earth's atmosphere. It effectively defines the rate with which electrons collide with neutral particles in the Earth's atmosphere and ionosphere and is quite important for accurate computations of ionospheric absorption values.

The first choice defines a model that uses *two* exponential terms. The second choice defines a model that uses only one exponential term, while the third choice defines a model that has a constant collision frequency model. The third choice *will* produce unrealistic results and should only be used by those who have a knowledge of the applications through which such a model can be used.

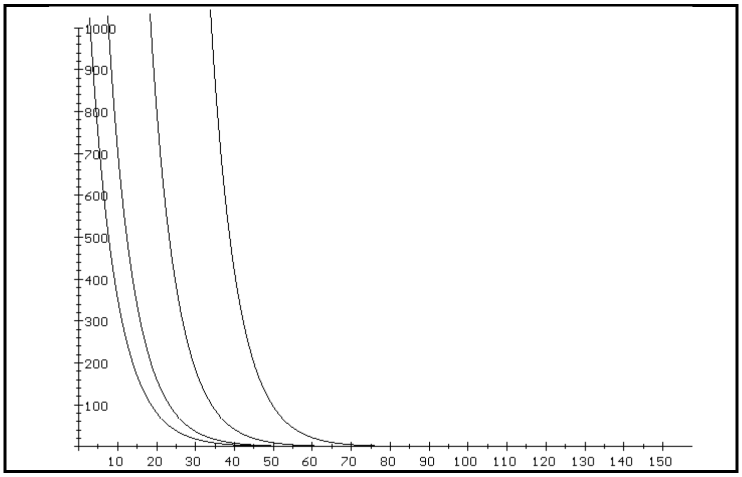


Figure 3.0: ***Collision Frequency Profiles using 2-exponential terms for frequencies from 10 to 0.1 MHz.***

By default, the model with two exponential terms is used. The difference between the first and second models (supporting two and one exponential terms respectively) is almost negligible. Figure 3.0 shows the collision frequency profile for transmission frequencies that vary from 100 KHz to 10 MHz. The lines are defined from left to right as follows: 10 MHz, 5 MHz, 1 MHz, 100 KHz. Altitude above the surface of the Earth is indicated by the bottom scale (from 0 to 150 km). Collision frequency is indicated by the vertical scale. As can be seen, as the frequency of the ray is increased, the effect of the collision frequency decreases so that higher frequencies do not play as large a role in collisions as low frequencies.

For those who are familiar with the exponential models of collision frequency, the exponential terms and reference heights which define the shape of these profiles can be adjusted if necessary using other options in this Comprehensive Options menu.

3.3.18.4 Electron Density Model

This is the option that lets you choose which type of electron density model to use in PROPLAB's comprehensive ray-tracings. The default is one of the three-dimensional models. These models are discussed in detail in Section 3.3.4.2. Consult that section for more information regarding the type of models to select.

3.3.18.5 Integration Method

PROPLAB PRO's comprehensive ray-tracing technique contains numerous complex equations that must be integrated in order to ray-trace signals. These methods are a little bit older but produce reliable results. The first choice selects the Runge-Kutta integration method while the second choice selects the Adams-Moulton method. The Runge-Kutta method is slower than the Adams-Moulton method, but produces a prodigious amount of information if you have instructed PROPLAB to save the ray-tracing results to the text file "RESULTS.OUT". You can choose to use either of these two methods, however the Adams-Moulton method tends to be slightly faster and perhaps only marginally more accurate than the Runge-Kutta method. The Adams-Moulton method is the default integration method.

3.3.18.6 Display Method

There are five available ways in which PROPLAB PRO displays ray-tracing results while using the comprehensive ray-tracing technique. They are described below.

The first method does not graphically display any ray-tracing information on-screen. It instead simply computes the ray-tracing paths *numerically* and saves the results to the file "RESULTS.OUT" *if and only if* you tell PROPLAB to create this file when you are answering the prompts that define the elevation angles to use, etc. While PROPLAB is computing the ray-paths, nothing will be displayed. You may therefore think PROPLAB has crashed your computer depending on the length of time required to complete the ray-tracings. This method is not recommended as it does not graphically show you any ray-tracing results. But it might be useful for those who are only interested in numerical results.

The second display method graphically displays rays traced through the ionosphere by assuming you are looking at the ray *cross-ways* from the ground. That is, it appears as though you are an observer looking at the traced rays perpendicularly. In this mode, you cannot discern lateral deviations easily (if at all). But you can determine the altitude the rays travel. This mode can also be simulated using the three-dimensional grid by appropriately rotating the display axes.

The third display method graphically displays rays traced through the ionosphere by assuming you are looking directly *down upon the rays* from above. In this mode, you cannot discern the altitude of the rays. This mode is useful if you are interested in the extent to which rays are being laterally deviated. However, the three-dimensional grid will also let you look directly down upon the rays by rotating the grid appropriately.

The fourth display method is one of two available *three-dimensional* graphical modes. This mode displays the progress of the traced rays using the rotatable three-dimensional grid. This lets you observe ray behavior from almost any conceivable viewing angle or perspective.

The fifth display method is the second available *three-dimensional* graphical mode. It is similar to the last display mode described but differs in one important aspect. In this mode, ray paths are displayed *while they are being integrated* . In the fourth display mode, ray-paths are only displayed at specific points along the ray-path (ex. entering/exiting the ionosphere, progress toward ray reflection, the location where the ray reverses direction, etc). The fourth display mode might therefore trace a more course-looking ray-path. This fifth display method smooths out the ray-path and displays as much ray-path information as possible. This is the recommended and preferred three-dimensional display mode.

3.3.18.7 Transmitter / Receiver Height

PROPLAB PRO will let you vary the height of the transmitter or the receiver to values from 0 kilometers to values as high as 1,000 kilometers. However, prudence must be exercised when selecting transmitter or receiver heights. For example, selecting a transmitter height that is deeply within the ionosphere (for instance, near the F2 layer maximum of electron density several hundred kilometers high) may force the transmitter to attempt to transmit signals while it is within the evanescent region. Transmissions and ray-tracings are not possible if the transmitter is within such a region. Such conditions can occur when the transmitter is within a region of the ionosphere where the critical frequency (at the transmitter) is near the transmitter frequency.

By selecting wise transmitter heights, it may be possible to simulate the behavior of satellite transmissions. It is interesting to see how different the behavior of signals can be if the height of the transmitter is only raised several tens of kilometers.

The receiver height can also be defined here. There are some known problems with adjusting the receiver height above the recommended 0-kilometer level (which defines the transmitter as residing on the surface of the Earth). For example, PROPLAB PRO Version 2.0 sometimes will not properly *end* ray-tracing when the ray's closely approach the receiver location. These problems do not appear if the receiver is left on the surface of the Earth. However, no harm can be done if you play with different receiver heights. We will leave the choice of whether or not to play with the receiver height up to you. Keep in mind, however, that adjusting the receiver height may result in some ray tracings that are terminated prematurely or incorrectly (accuracy is not compromised).

3.3.18.8 Ray-Tracing Rate / Steps per hop

The comprehensive ray-tracing technique traces rays through the ionosphere by integrating the rays through specified distances. The default distance is 1 kilometer and this forms the basis for the *ray-tracing rate* . Larger values force PROPLAB to trace rays through the ionosphere using larger steps while smaller values force PROPLAB to use smaller steps.

The *steps per hop* prompt define how many times PROPLAB should attempt to solve the ray-tracing problems before giving up. The default is 5,000 times, which should be enough for most (if not all) cases. If this value is reduced too much, PROPLAB may give up trying to solve ray-tracing problems before they are solved. If, during a ray-tracing session, you get an error indicating that PROPLAB reached the iteration limit, increase this value in steps of approximately 500 to 1000. If this value is left at 5,000, PROPLAB should handle almost all instances without prematurely giving up.

3.3.18.9 Magnetic Pole Lat / Lon

This suboption lets you define the exact location of the Earth's *northern* geomagnetic pole. It is only used if you are using a ray-tracing model that requires the Earth's magnetic field as input. Positive values represent northern latitudes and western longitudes. Negative values represent southern latitudes and eastern longitudes. Results may differ considerably from reality if the southern magnetic pole or other geographical locations are used to represent the magnetic pole.

3.3.18.10 Maximum / Minimum Ray-Tracing Step Length

This option lets you change the *maximum* and *minimum* allowed step lengths during comprehensive ray-tracing. When PROPLAB is tracing through regions which are relatively free of refractive effects (as occurs, for example, when ray-tracing below the ionosphere), it is permitted to increase the stepping length to the specified *maximum* value. When PROPLAB is tracing rays through regions of the ionosphere where small increments in distance result in substantial changes in refractive indices, PROPLAB is permitted to decrease the stepping length to the specified *minimum* value in order to properly integrate the equations through the rapidly changing regions of the ionosphere. The defaults of 10 km and 0.01 km for the maximum and minimum step lengths will suffice under almost all circumstances. Decreasing these values may increase the accuracy of traced rays slightly but will slow down the computations.

3.3.18.11 Left Latitude / Longitude of Display

PROPLAB PRO's comprehensive ray-tracing method requires a *viewing window* that encompasses the geographical region where the signals are being traced. This window is defined by stating the latitude and longitude of the left-side corner coordinates of the ray-path and the right-side corner coordinates of the ray-path. These two sets of corner coordinates form a box within which the rays are traced.

PROPLAB automatically computes these corner coordinates for you, so you will seldom need to change them. However, if you ever do need to alter them, this option and the option described in Section 3.3.18.12 (below) will let you do this.

We do *not* recommend you play with these values unless you know what you are doing. Doing so haphazardly could cause PROPLAB to incorrectly draw the display grids or even fail to properly trace the rays. No harm can be done, however.

3.3.18.12 Right Latitude / Longitude of Display

This option defines the latitude and longitude of the right-side corner of the viewing window described in Section 3.3.18.11. Refer to that section for details. Positive values (for both the left and right-side corner coordinates of the window) represent northern latitudes and western longitudes while negative values represent southern latitudes and eastern longitudes.

3.3.18.13 Grid Distance and Ticks

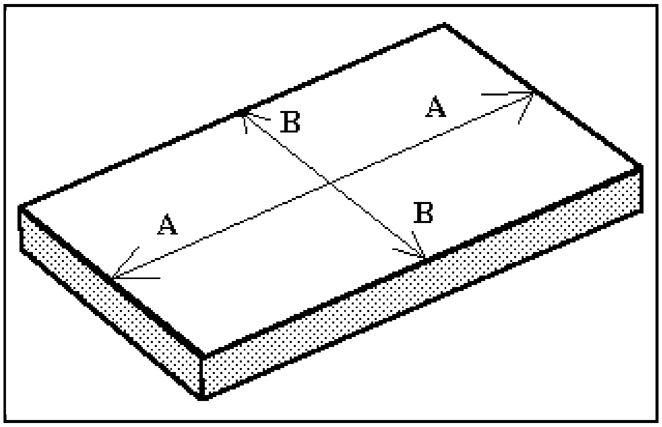
This option applies primarily to the three-dimensional display grids on which rays are traced. It lets you specify the maximum grid distance to display on-screen. This distance must be less than or equal to 20,000 kilometers. Since PROPLAB PRO's comprehensive ray-tracing engine will only trace short-paths and since the half-circumference of the Earth is 20,000 kilometers, this maximum permitted grid distance corresponds to the maximum traceable short-path distance. It should suffice for most applications.

For example, if the distance between the transmitter and receiver is 7,000 kilometers, it would be wise to specify a grid distance of at least 7,000 kilometers or more. If you specify a distance less than 7,000 kilometers, the receiver location will not be included on the grid.. It would be wiser to specify distances that are several thousand kilometers *greater* than the transmitter-receiver distance so that ray's which do not precisely reach the receiver distance will continue to be traced until they hit the ground some distance beyond the receiver. It is generally good practice to specify a distance approximately 4,000 kilometers beyond the receiver. This corresponds to the approximate maximum one-hop limit.

The two remaining prompts let you define how PROPLAB should label the grids. The first of these two prompts asks you to specify the distance between labelled ticks on the distance scale. For example, if the transmitter-receiver distance is 7,000 kilometers and you want PROPLAB to display labelled tick marks (or lines) every 1,000 kilometers toward the receiver, you would specify 1000 here. This lets you instantly estimate the ground location and distance the rays are from the transmitter *during the ray-tracing phase* .

The last prompt defines the *lateral distance* grid. Since traced three-dimensional rays can deviate away from the great-circle path, the lateral distance grid gives you the ability to define how large this lateral deviation grid should be.

The Figure beside this paragraph illustrates this further. The line drawn lengthwise down the center of the grid in this Figure defines the great-circle distance between the transmitter and



receiver (which are located at the ends of the "A" line). The distance grid runs along the length of the A line. The lateral deviation grid distance is the distance represented by the "B" line. Rays which deviate away from the great circle path will begin to turn away from the A line and begin crossing through a portion of the distance represented by the B line. The last prompt in this option defines how far across the B line should span (in kilometers). By making the distance smaller, you are able to discern smaller lateral changes in the traced rays. By making the distance larger, you are able to discern larger lateral deviations in traced rays. If the traced rays begin to laterally deviate beyond the given lateral grid distance, you will need to increase the distance of the lateral grid so that you can better observe where the traced rays propagate.

The lateral grid distance you specify is *centered* across the A line above. For example, by specifying a lateral grid distance of 500 kilometers, the B-line distance will be 500 kilometers, spanning 250 kilometers on each side of the great-circle "A" line.

3.3.18.14 Distance between Ticks in Altitude

This option defines how many ticks (or lines) should be used to define the altitude wall of the three-dimensional grid. The default is 20 kilometers which provides reasonably good resolution. In other words, a line would be drawn on the altitude wall every 20 kilometers in altitude.

The maximum height displayed on the altitude wall is determined by the HMax parameter given below.

3.3.18.15 3-D Rotation Angles for the X / Y / and Z Axes

This suboption defines how you want to view the three-dimensional grid. It lets you rotate the three dimensional grid in almost any conceivable fashion, effectively changing the viewing perspective of the grid. This gives you the ability to view traced rays at almost any angle desired.

The default rotation angles are -60, 0, and 20 degrees for the X, Y, and Z axes respectively. These rotation angles provide a good view of the traced rays (both in altitude, distance, and lateral deviation).

Note that PROPLAB will accept almost any set of angles here. However, some exotic angles may cause PROPLAB to improperly draw grid borders, labels or other things. Even so, no harm can be done (it may just be more difficult to see), so feel free to play with this section until you find values that are aesthetically pleasing.

3.3.18.16 Zoom Factors and X / Y Axis Offsets

PROPLAB PRO has the ability to display three-dimensional grids that are zoomed in or out. The X and Y axis offsets permit zooming centered on any location of the three-dimensional grid.

Zoom factors must be specified in percentages, where zero percent represents an *unzoomed* screen. A zoom factor of 100 percent will zoom into the three-dimensional grid (centered on the center of your monitors screen) by a factor of 2 times the normal. Similarly, a zoom factor of -50 percent will cause PROPLAB to *zoom out* by 50 percent (thereby making the three-dimensional grid half the size on the screen).

The X and Y axis offsets are relative to the middle of your monitors screen, *not* the middle of the three-dimensional grid. They are also both stated in percentages of screen widths and heights.

The X-axis offset defines the center location of the X-axis of your screen. The default value is 0.00 percent, which corresponds to the 320th horizontal pixel on VGA displays. A value of +30.0 percent corresponds to a location 30% to the *left* of the 320th horizontal pixel while a value of -30.0 percent corresponds to a location 30% to the *right* of the middle of your screen.

The Y-axis offset is defined similarly. The default value of 0.00 percent corresponds to the 240th vertical pixel on VGA displays. A value of +30.0 percent corresponds to a location that is 30% *above* the middle of your screen while a value of -30.0 percent refers to a location that is 30% *below* the middle of your screen.

By adjusting these variables, it is possible to zoom in to features of traced rays that might be difficult to see under normal circumstances.

3.3.18.17 HMax (and Altitude Grid) / Ym / and foF2 Layer Shaping Factors

This option will likely only be used by those who have a firm knowledge of the mathematical representations of ionospheric electron density profiles. These options are used primarily by the Quasi-Parabolic and Alpha-Chapman electron density models and must be adjusted to the appropriate values *prior* to performing any raytracing. The two-dimensional electron density models (CCIR and URSI) require the *foF2* (critical frequency of the F2 layer) parameter only. The other two parameters (HMax and Ym) are not used in the URSI or CCIR two-dimensional electron density models.

The HMax parameter refers to the altitude above the surface of the Earth where the electron density reaches a maximum (usually in the F2 layer). This parameter is also used to adjust the height of the altitude grid "wall" on three-dimensional displays. For example, to display a three-dimensional grid up to an altitude of 400 km, enter 400 at this prompt. The Ym parameter defines the *thickness* of the ionospheric layer being modelled. And the foF2 parameter defines the critical frequency of the ionosphere at the HMax altitude. The foF2 determines the maximum electron density of the layer through the formula: 1.24E+10 x foF2.

These parameters should apply to the *midpoint* of the ray paths in order to produce accurate single-hop ray-tracings.

If you are using a three-dimensional electron density model, these parameters will not be used. For novices in ionospheric radio propagation, using a three-dimensional model is highly recommended.

3.3.18.18 Ground Gyrofrequency at the Equator

The *gyrofrequency* refers to the number of times charged particles such as electrons and ions spiral around the Earth's magnetic field lines per second. The rate with which these particles spin around the magnetic field lines is related to the strength of the Earth's magnetic field. The gyrofrequency at the ground and on the equator is used by PROPLAB as a reference in some of its ray-tracing operations. Altering the given value should only be done by those who know what the implications are of doing so. In most (if not all) instances, this option will not need to be used.

3.3.18.19 Electron Collision Frequency and Profile Shaping Parameters

Electron collision frequency profiles are used by PROPLAB to model the frequency with which electrons collide with neutral particles in the atmosphere. This phenomenon is critical for determining ionospheric absorption of radio signals that travel through the ionosphere.

The 19th and 20th suboptions of the Comprehensive Options menu define the electron collision frequency model parameters that determine the overall shape of the electron collision frequency models used in PROPLAB. We recommend these values are not touched unless you are familiar with electron collision frequency profiles and the models used to derive them.

The equations used to derive the electron collision frequencies are shown below:

$$ColFreq = \frac{\left(\frac{N}{\exp(A*(Height-RefHeight))}\right)}{2\pi*Xmitfreq*10^6}$$

This equation gives the electron collision frequency for *one* exponential term and therefore corresponds to the collision frequency model containing only one exponential term. In the above equation, ***N*** corresponds to the collision frequency at the height corresponding to ***RefHeight***. The frequency of the signal being broadcast into the ionosphere is defined by ***Xmitfreq*** and is given in MHz (the multiplication by 10^6 converts MHz to Hz). The variable ***A*** defines the value of the exponential term that determines the shape of the profile at the altitude ***RefHeight***.

The equations used to derive the electron collision frequencies with *two* exponential terms follows below:

$$ColFreq = \frac{(N1*\exp(-A1*(Height-RefHeight1)))+(N2*\exp(-A2*(Height-RefHeight2)))}{2\pi*Xmitfreq*10^6}$$

In this equation, ***N1*** corresponds to the collision frequency at the height corresponding to ***RefHeight1*** and ***A1*** is the exponential value that gives this section of the model its shape at ***RefHeight1***. ***N2*** is the collision frequency at the height corresponding to ***RefHeight2*** and ***A2*** is the exponential value that gives the model its shape at the height ***RefHeight2***. And as in the previous equation, ***Xmitfreq*** is the frequency of the signal being transmitted through the atmosphere in MHz.

With this information in-hand, the Comprehensive Option menu choices (#19 and #20) can be appropriately changed to yield the collision frequency profiles you desire.

3.3.18.20 Three-Dimensional Data (Important!)

Option #21 of the Comprehensive Options menu is a ***VERY Important*** section that must be changed every time you change the transmitter/receiver locations or ionospheric profiles. ***Failing to do so will result in inaccurate ray-tracings!***

This is the section where you are asked all of the critical questions which determine how PROPLAB builds the ionospheric profiles necessary to support three-dimensional comprehensive ray-tracing.

Before proceeding further, make sure you have read and understood Section 3.4.13 (Understanding the Generation of Ionospheric Profiles). That section will teach you everything you need to know about how PROPLAB generates ionospheric profiles for three-dimensional ray-tracing so you will be prepared to properly respond to these important prompts.

PROPLAB first shows you the current 3-D data settings. This is followed by the bearing from the transmitter to the receiver as well as the computed great-circle distance between these two points. Check to make sure it is all correct. If it is not, use Main Menu Option #8 (or #3) to change the geographical locations of the transmitter and receiver to the correct latitudes and longitudes. Then re-enter this section to specify the three-dimensional data.

PROPLAB first asks you to specify how many degrees adjacent (perpendicular) to the bearing (of the great-circle path) ionospheric profiles should be constructed. For example, if you specify 10 degrees here, PROPLAB will construct ionosphere profiles spanning 10-degrees ***on BOTH sides of the main great-circle bearing***. It will therefore construct profiles covering a total azimuthal span of 20 degrees (10-degrees per side). A value of 1 degree will cause PROPLAB to construct profiles only one degree on either side of the main bearing. If the main bearing was therefore 315 degrees from the transmitter to the receiver, PROPLAB would construct ionospheric profiles at bearings of 314, 315 and 316 degrees (one degree on each side of the main bearing).

PROPLAB next asks you how many profiles you want to build along the bearing range. The *bearing range* refers to the total azimuthal span for which profiles will be constructed. In the first example above, the bearing range would have been 20 degrees (10-degrees per side). In the second example, the total bearing range would have been 2 degrees (1-degree per side). This prompt is therefore essentially asking you what the stepping rate should be between successive sets of azimuthal ionospheric profiles. The stepping rate can be computed by dividing the bearing range by the number of profiles you want to build along the bearing range. For example, if the bearing range is 20 degrees and you want to build 50 sets of profiles along that range, PROPLAB would use a stepping rate of (20 / 50) 0.4 degrees. Assuming the main bearing is 315 degrees, the first set of profiles would be built along the bearing (315 - 10) 305 degrees. The second set of profiles would be stepped by 0.4 degrees and would therefore be built along the bearing 305.4 degrees. The third set of profiles would be built along the bearing 305.8 degrees, etc - in the end resulting in about 50 sets of ionospheric profiles covering the bearing range from 305 to (315 + 10) 325 degrees in 0.4 degree increments. This prompt is important for preventing data gaps in ionospheric profiles.

The next prompt posed by PROPLAB asks you to specify the distance (in kilometers) *behind* the receiver to begin computing the various sets of ionospheric profiles. In most instances, a value of 0 kilometers will be specified here, indicating that the first profile generated along each bearing should be directly above the transmitter.

The following prompt asks you to specify the distance *ahead* of the transmitter (in kilometers) to end ionospheric profiles. The total distance specified here (defined as the distance ahead of the transmitter minus the distance behind the transmitter) determines the length of one *segment* as described in Section 3.4.1.3.

PROPLAB next asks you to specify the number of individual ionospheric profiles you want to build along the total distance of the specified *segment*. You can instruct PROPLAB to build up to 46 individual ionospheric profiles along the length of a segment. It therefore defines the resolution of the ionospheric profiles used in three-dimensional ray-tracing. For example, if the total distance of a segment was 8,000 kilometers and you state that you want to build 20 profiles along this distance, PROPLAB will generate one ionospheric profile every (8000 / 20) 400 kilometers. The resolution can be increased by increasing the number of profiles from 20 to 46. This reduces the distance between individual successive ionospheric profiles from 400 kilometers to 174 kilometers.

The last prompt posed by PROPLAB asks you how many segments you want to build ionospheric profiles for along each bearing. In the above example, if we specified 2 segments (each of which is 8,000 kilometers in distance), we would be able to trace rays along any of our bearings out to a distance of (8000 x 2) 16,000 kilometers.

After answering these prompts, PROPLAB is ready to begin building ionospheric profiles. This is accomplished by actually instructing PROPLAB to begin a comprehensive ray-tracing session (use Main Menu Option #1).

3.4 PROPLAB's Main Menu Functions

The Main Menu of PROPLAB gives you access to all of the functions of PROPLAB and is responsible for loading and executing the appropriate subprograms when requested. It consists of nine options which are described below.

3.4.1 Ray Tracing Signals

PROPLAB is very flexible in the way it permits signals to be traced through the ionosphere. Before ray tracing can be accomplished, it is important to setup the appropriate parameters in the Options Menu (see Section 3.3) so that PROPLAB knows all about the signal you are transmitting from one point to another.

As has been noted in previous sections of this manual, there are two main ray-tracing methods that are available: a *simple* technique and a *comprehensive* (or *complex*) technique. The first option of the Main Menu lets you choose which type of ray-tracing technique you want to use. Use the simple method if you are more concerned about a quick analysis of the way signals are reflected from the ionosphere. Use the comprehensive method if you need accurately ray-traced signals that show you more precisely where signals are going. Use a three-dimensional model of the comprehensive method to see where signals go in three dimensions.

3.4.1.1 Ray Tracing Signals using the Simple Ray-Tracing Technique

There are three different methods you can use to trace signals through the ionosphere. The first is by holding the frequency of the signal and the time of the transmission constant, and sweeping the elevation angle of the transmission. The second is by holding the elevation angle and time of transmission constant and sweeping the frequency of the signal. And the third is by holding the elevation angle and the frequency of the signal constant and sweeping the time of the transmission. By "sweep", we mean to increase the value from a lower value to a higher value in user-specified steps or increments.

Each of these three methods provide valuable and different results. For example, most radio transmitter antennas are capable of transmitting in specific or preferred directions. That is, their radiation patterns are usually higher in certain directions. These are called directional antennas. Omni-directional antennas are associated with radiation patterns that are essentially equal in all directions. That is, the power transmitted away from the antenna is equal in all directions. By selecting ray tracing by sweeping elevation angles, you can essentially analyze the performance of specific transmitters by sweeping transmission elevation angles in accordance with the radiation pattern of the antenna. To clarify, let's assume that you have an antenna that is most efficient in transmitting between 4 and 12 degrees of elevation above the horizontal. That is, most of the power is radiated in a field that lies between 4 and 12 degrees in elevation. Now you want to determine propagation quality of a signal being propagated from your location to a distant region 3,000 kilometers away, but you are uncertain whether your transmitter will be able to send a signal that distance. Using this first function to sweep elevation angles, you can set up PROPLAB to begin tracing rays through the ionosphere beginning at an elevation angle of 4 degrees and ending when the elevation angle reaches 12 degrees. The step rate you choose to use is entirely up to you. If you want PROPLAB to trace 3 rays on-screen between this range, you would select a step rate of 4 degrees of elevation per trace. For 16 traced rays (and hence, greater resolution in the results), you would select a step rate of 0.5 degrees of elevation per traced ray.

The usefulness of sweeping elevation angles is not restricted to the above example. There are many other useful ways to use this function. For example, if you need to know exactly what distance your signal strength is a maximum on a given frequency, you would select this option to sweep elevation angles. Since signal strength is proportional to the concentration of rays that strike the ground per unit area, you would look for a pattern similar to Figure 2.5, where the rays become concentrated. The area where the rays are most concentrated is the location (and distance) of maximum signal strength.

Another way to use this function is to determine what angle of elevation to use for signals to reach a specific distant location. Most propagation programs give you a single transmission angle of elevation for signals to reach destinations. Unfortunately (as you will discover while using PROPLAB), those angles of elevation can often be significantly in error because the algorithms used are empirical in nature and attempt to lump together all ray paths. In other words, those programs do not consider individual ray paths in the ionosphere and as a result must estimate elevation angles. The method employed by PROPLAB is one of the most accurate methods available and should yield good results under most conditions. Because PROPLAB traces each ray individually through a dynamic ionosphere, the angle of elevation required to reach a specific distant destination can be accurately pinned down. Simply sweep a range of elevation angles and look for rays that strike close to the desired destination.

PROPLAB uses the arrow at the bottom of the screen (in the distance scale as has been shown in previous Figures), along with a vertical dotted green-colored line, to mark the exact location of the destination point. It is therefore easy to determine the proximity of traced rays to the destination by simply comparing the location of the rays with the arrow or green dotted line.

Sweeping frequencies is as useful as sweeping elevation angles. Sweeping frequencies can tell you a great deal about how the ionosphere responds to different signals. For example, by sweeping frequencies, you can determine what frequency to use to penetrate through dense layers of sporadic-E, or through other ionospheric layers. Since long-distance communications occurs best through F2-layer reflections, sweeping frequencies can help you determine what frequencies to use to penetrate through the D, E, and F1 layers for reflection from the F2 layer. During the day, when ionization of the D, E, and F1 layers is highest, this software feature can significantly help you isolate optimum frequencies for specific paths.

Sweeping time from hour to hour, or minute to minute lets you analyze the behaviour of the ionosphere over time and how it responds to the signals you transmit. This is a very useful feature for determining what times of the day certain frequencies open up for long-distance communications, or for observing what happens (for example) at sunrise or sunset and how signal propagation radically changes during these periods of time.

The fourth option available in this Ray-Tracing Menu (Generate Oblique Sounder Ionogram) is a powerful function that requires an entire section within this manual to adequately describe. Refer to Section 8 for details regarding this function.

3.4.1.2 Ray Tracing Signals using the Comprehensive Ray-Tracing Technique

The menu associated with the comprehensive ray-tracing technique lets you trace rays through the ionosphere by sweeping elevation angles, frequencies, *azimuths* or any (or all) of these three together.

The prompts associated with the elevation and frequency sweep selections are similar to those for the simple ray-tracing method and need no further explanation here. The option to permit tracing rays by sweeping azimuths is new to PROPLAB PRO Version 2.0, but is self-explanatory. Enter in the starting and ending azimuths (clockwise from true north - east is 90 degrees azimuth) you want to transmit toward in degrees. Also enter in the rate with which you want to step the azimuth from the starting to the ending azimuth (in degrees).

PROPLAB PRO Version 2.0 prompts for several additional items that are not present in the simple technique (and in fact have not ever been present in prior releases of PROPLAB). These prompts are described below.

After selecting which component to sweep (elevation angles, frequencies or azimuths), you are asked to input the "azimuth of the transmitting antenna" in degrees clockwise from true north. This is the azimuth of the main radiation lobe of the transmitting antenna. For instance, if your antenna has a radiation pattern that radiates most of the transmitted power directly toward the east, you would specify an azimuth of 90 degrees. If your antenna is rotatable, specify the current azimuth of the antenna's main radiation lobe. This is an ***important parameter*** that must not be overlooked. PROPLAB PRO uses this information to compute the field strength of the signal. Entering the proper antenna azimuth as well as the proper type of antenna is necessary if PROPLAB is to produce reliable results.

The second prompt asks you if you want to "Store text results in the file 'results.out' ?" When using the comprehensive ray-tracing technique, PROPLAB PRO will optionally create a text file and write various bits of information to that file while rays are being traced through the ionosphere. For example, whenever a ray reaches an apogee or perigee (maximum height or minimum height respectively), is reflected by the ground, penetrates the ionosphere, or reaches the receiver, PROPLAB writes information to this file. Information written includes such parameters as the ground range, the latitude/longitude of the ray, the polarization of the ray, ionospheric absorption encountered, geometrical path distance, phase path, group path and ray deviations and bearings, etc. This information can be used to gather more detailed data regarding a particular traced ray. If you want this type of information stored, select "y"es at this prompt. ***Be aware*** that the size of this file can become quite large fairly quickly (particularly if the Runge-Kutta integration technique is used) if many rays are traced with this option enabled.

For each comprehensively traced ray, PROPLAB writes specific information to a binary file in the PROPLAB directory. This information can then be later read and analyzed by PROPLAB functions which will (for example) plot the locations of traced rays on global maps, produce contoured field-strength maps, etc. Since you cannot stop PROPLAB from writing this information, you must only decide whether you want to "A"ppend the results to the file or "C"reate an entirely new file (effectively truncating any existing data and rewriting the file from scratch). If you choose to "C"reate the ray-database file, PROPLAB will erase any contents that may already exist in that file. So be careful. If you recently performed a large ray-tracing session and do not want to lose that information, but you do want to trace a *different* set of rays along a *different* path, then go to the DOS prompt and rename the database file ("RAYOUT.DAT") to something else before responding to this prompt. To abort this prompt without doing anything, press the ESCape key. For most applications, you will probably "C"reate a new database file each time you trace rays through the ionosphere. In cases where you may be performing several ray-tracing sessions that are all related (that is, they have the same or similar paths, transmitter/receiver locations, frequencies, etc), you may want to "A"ppend the results to the existing database file so that the database of information is supplemented with the new results.

After inputting the starting, ending, and stepping values, you are asked whether or not you want to "Use the existing electron density profiles ?" This is a very important question that you must answer properly. But before you can give a qualified answer, you must better understand how and why PROPLAB PRO uses electron density profiles. The next section (Section 3.4.1.3) discusses this in detail. Please read that section next before proceeding. The rest of this section should then be easily understood.

If you choose to use the existing electron density profiles, PROPLAB will immediately load up the ray-tracing engine and begin ray-tracing the signals through the ionosphere using the existing set of ionospheric profiles. If you choose *not* to use the existing electron density profiles, PROPLAB asks you whether or not to delete the existing profiles from the PROFDATA subdirectory before building the new profiles. If you need to increase the resolution of the profiles (ex. decrease the steps between successive profile azimuths), select "n"o at this prompt so PROPLAB will not delete the existing profiles. By specifying "n"o, PROPLAB asks you whether or not it should overwrite existing profiles if it encounters any. If you instruct PROPLAB *not* to overwrite profiles, the speed of the profile-generating phase will increase since any existing profiles that match those that are requesting to be built will be skipped (not overwritten). If you want to make sure that all of the profiles are fresh and in-tact, instruct PROPLAB to overwrite any profiles that already exist.

Please note that the above prompts apply mostly to three-dimensional ionospheric models. Two-dimensional models are not quite as demanding, as only a single profile file is built (by the name of "IRIPROF.DAT" in the main PROPLAB directory). The prompt asking whether or not to delete existing profiles does not apply when two-dimensional models are used and should be answered with a "N"o (meaning you don't want to delete any existing *3-D* profiles).

Following these prompts, PROPLAB begins to automatically compile the required profiles in the PROFDATA subdirectory (for 3D profiles or in the main PROPLAB directory for 2D profiles). After it finishes building the profiles, it automatically loads the ray-tracing engine and begins comprehensively tracing the signals through the ionosphere.

3.4.1.3 Understanding the Generation of Ionospheric Profiles

The comprehensive ray-tracing technique differs from the simple ray-tracing technique in that it cannot compute the characteristics of the ionosphere "on the fly" as the simple method can. The reason has to do with memory constraints. The comprehensive ray-tracing engine is an exceptionally complex and large software program. In order to fit it all into memory, some desirable features had to be removed such as the ability to compute on-the-fly ionospheric profiles. We could have used overlays to add this ability, but the use of overlays would have dramatically decreased the performance and speed of the ray-tracing engine. Future releases of PROPLAB may include an overlaid version that supports on-the-fly profile generation. For the current version of PROPLAB, the ionospheric profiles are not generated on-the-fly but must still be provided in some way so that PROPLAB *can* in fact compute profiles for any distant point along a given azimuth. The method described here is the simplest and most rapid method we could devise that does not sacrifice accuracy.

The following discussion assumes a three-dimensional ray-tracing is being performed.

In a realistic three-dimensional ionosphere, the character of the ionosphere is constantly changing. Electron densities (which are major players in the refraction of radio waves) vary widely from place to place. They are high near the equators, low near the poles, highest near the magnetic equator in the afternoon, lowest in the high latitudes near dawn, and are constantly changing intensity. These profiles, however, are extremely important if realistic rays are to be traced through such a dynamic ionosphere.

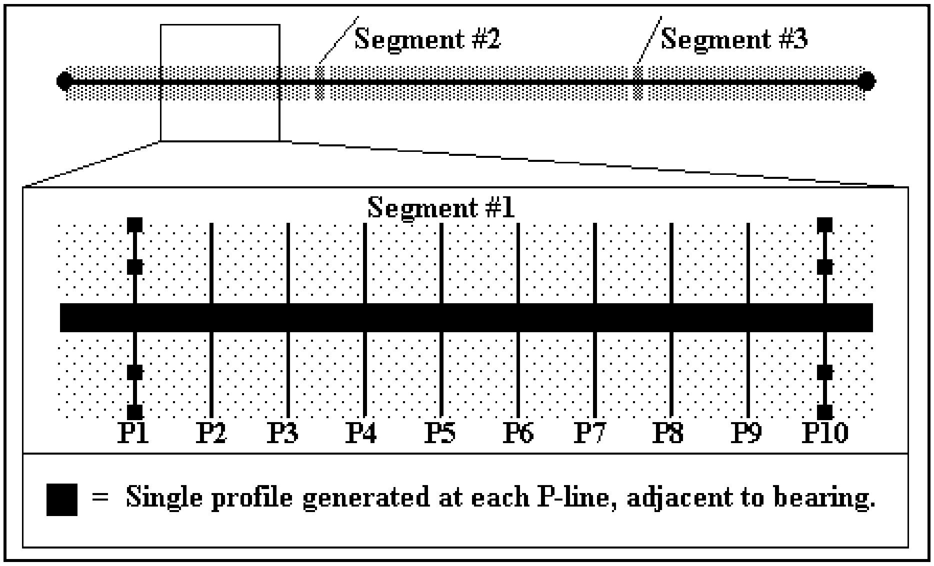


Figure 3.1: *How PROPLAB Segments Paths and Computes Profiles* .

To generate these profiles, PROPLAB PRO splits up a specific path (along a particular azimuth) into a user-defined number of segments (see Figure 3.1). Within each of these segments, PROPLAB computes a user-defined number of ionospheric profiles. Each of the computed profiles contains several other profiles immediately adjacent to the main bearing of the signal. Figure 3.1 shows this in greater detail. The top part of this figure shows the entire path, divided into 3 segments. The inset shows a part of Segment #1 in greater detail. In the inset, the solid line represents the main bearing (the great-circle path) of the signal. In order to compute the spatial gradients of electron density along this main bearing, it is necessary to know the ionospheric characteristics immediately adjacent to this main bearing. So PROPLAB computes ionospheric profiles along successive sections of each segment as shown by the P-lines in Figure 3.1. Along each of these P-lines (adjacent to the main bearing), PROPLAB computes profiles a short distance from the main bearing, as indicated by the small squares along the P1 and P10 lines. Although it is not shown, profiles are computed in similar locations along each P-line.

So now PROPLAB knows the ionospheric profiles along the main bearing and it also knows the characteristics of the ionosphere at small distances away from the main bearing. This is all of the information that is necessary for signals to be traced in three dimensions, since it allows us to compute all of the required spatial gradients of electron density along the path the signal travels (*provided* it does not deviate from the given azimuth).

The ionospheric profiles produced by PROPLAB tend to span lateral distances of up to about several hundred kilometers away from the main bearing. That is, the distance between the outermost squares in Figure 3.1 will vary but typically span approximately several hundred kilometers, depending on the geometry of the path. This is important to realize since it will help you understand whether or not you might need to build other ionospheric profiles parallel to the main bearing.

Signals that travel through the ionosphere frequently travel paths that do not strictly correspond to the anticipated great-circle path. Ionospheric tilts, effects of the Earth's magnetic field, and other anomalies can cause rays to deviate from the great-circle path. These deviations must be taken into consideration when generating ionospheric profiles. This is important because if PROPLAB cannot find an ionospheric profile for a specific part of the ray path, it will produce a warning indicating that the "ray went out of the grid bounds". In other words, PROPLAB is unable to determine the necessary ionospheric parameters to accurately ray-trace signals through the ionosphere. This can result in inaccuracies in the traced rays.

To overcome this difficulty, the Comprehensive Options Menu (Main Menu #8, Suboption #18) contains an option (option #21) that lets you set up exactly how PROPLAB should create the ionospheric profiles. PROPLAB lets you develop ionospheric profiles over a range of bearings that are centered on the main great-circle bearing to the receiver. For example, if the bearing from the transmitter to the receiver is 100 degrees, you can use this option to develop ionospheric profiles that might span, for example, a 5-degree bearing spread on either side of the great-circle bearing. PROPLAB would then create ionospheric profiles spanning from 95 to 105 degrees. Another prompt presented within this option determines how many profiles to build along the bearing range. In other words, you are asked to type how many ionospheric profiles should be built between the 95 to 105 degree bearing range. The more profiles you build along the bearing range, the less likely PROPLAB is to trace a ray through a location where the ionospheric characteristics cannot be determined.

To help explain why PROPLAB might not be able to find an appropriate profile, refer to Figure 3.2. The two X's shown in this figure correspond to the transmitter and receiver locations. The great-circle path between these two points is represented by the imaginary straight line between the two X's. In this figure, we have generated eight ionospheric profiles that describe the characteristics of the ionosphere between the transmitter and receiver at eight different azimuths indicated by the eight shaded regions in Figure 3.2. When a sufficient number of profiles are generated along the bearing range, the profiles begin to overlap so that there are no regions between the transmitter and receiver that are devoid of ionospheric information. In other words, if the number of profiles is sufficient, PROPLAB will know everything it needs regardless of where signals may travel between the two points. If in Figure 3.2, the ray took a path that travelled above the right-side X, the ionospheric profiles would be able to describe the characteristics of the ionosphere consistently (there are no data gaps). However, if an *insufficient* number of profiles are generated, PROPLAB may begin to see gaps where the ionospheric profiles do not overlap. If traced rays encounter any regions where there are gaps (as the one shown in Figure 3.2), it will not be able to accurately compute the ionospheric characteristics.

This will degrade the accuracy (often very seriously) of the traced rays. It is therefore important that you specify a large enough number of profiles so that gaps are eliminated.

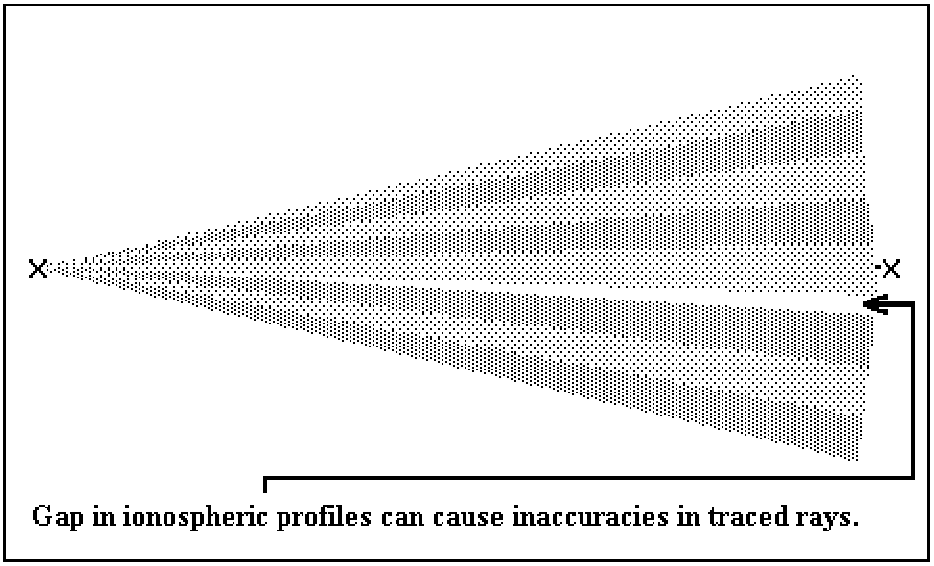


Figure 3.2: ***Gaps in Ionospheric Profiles (see text)***

You can calculate how closely spaced the various ionospheric profiles are (in bearing) to one another by dividing the bearing range by the number of profiles you are generating. For example, in the example above, we wanted to generate profiles covering a 5 degree spread on either side of the great-circle bearing. The total bearing spread is therefore 10 degrees (105 degrees - 95 degrees = 10 degree spread). By telling PROPLAB to generate 10 ionospheric profiles over this bearing range, PROPLAB will generate profiles every 1.0 degrees in bearing (10 degree spread / 10 profiles = 1.0 degree). PROPLAB will then generate the first profile at a bearing of 95 degrees, the second profile at 96 degrees, etc, until the bearing exceeds 105 degrees. You can increase the resolution of the profiles (that is, make them overlap more to reduce or eliminate gaps in data) by increasing the number of profiles. For example, by specifying 30 profiles instead of only 10, you effectively instruct PROPLAB to produce ionospheric profiles every 0.3333 degrees in bearing (10 degrees / 30 profiles = 0.3333 degrees per profile). PROPLAB would then create the first profile at 95 degrees, the second profile at 95.3333 degrees, the third profile at 95.6666 degrees, etc, until the bearing increased beyond 105 degrees. Hence, the lower the stepping rate, the higher the resolution, the greater the overlap in profiles, and the less chance there will be for data gaps.

The smallest stepping rate allowed by PROPLAB is a stepping rate of 0.1 degrees in bearing. Even for very long-distance paths near the 20,000 kilometer limit of PROPLAB's comprehensive ray-tracing engine, this stepping rate usually suffices. However, be aware that as the distance between the transmitter and the receiver increases (or rather, as the ray moves farther and farther away from the transmitter), the probability of the ray encountering data gaps increases. This is because as the distance increases, the amount each successive profile overlaps the preceding one decreases.

The above discussion illustrates how PROPLAB is able to compute ionospheric parameters for rays that deviate away from the great-circle path. However, we still do not know how PROPLAB computes the ionospheric profiles *along* each of these different bearings. We have, until now, assumed that PROPLAB simply knows the ionospheric characteristics at every possible point in distance between the transmitter and receiver on specific bearings adjacent to the great-circle bearing. This is essentially true because PROPLAB performs interpolation to make it true. But in reality, the interpolation performed introduces possible areas where traced rays may begin to deviate from reality. The following discussion explains why.

When setting up the parameters (in suboption #21 of the Comprehensive Options menu), PROPLAB prompts for the distance in kilometers along each bearing to compute the ionospheric profiles. This is followed by a prompt asking how many individual ionospheric "samples" should be taken along the specified distance (up to a limit of 46). For example, if on each desired bearing within the bearing range, you want PROPLAB to generate ionospheric profiles along a 15,000 kilometer path, you can instruct PROPLAB to generate up to 46 ionospheric profiles along that path. That amounts to one profile every 326 kilometers (15000 / 46 = 326). This means that each successive ionospheric profile is separated by 326 kilometers. In order to prevent gaps in data from appearing, PROPLAB must perform *interpolation* when rays are in-between ionospheric profiles (as would occur if a ray was part-way between profiles that were spaced 326 kilometers apart). This interpolation process is a source for possible inaccuracies in traced rays. The level of inaccuracy is proportional to the distance separating ionospheric profiles. In other words, the closer the spacing in distance is between successive ionospheric profiles, the more accurate the ray tracing will be. A spacing of 326 kilometers is a fairly hefty distance. The character of the ionosphere may change appreciably within this distance. Therefore, it would be wise to decrease the spacing between ionospheric profiles so that we obtain a more realistic sampling of the ionospheric characteristics. In this example, we are unable to decrease the distance between ionospheric profiles because we are already using the maximum allowed number of profiles (46). We are in luck, however, because PROPLAB will let you split up the 15,000 kilometer path into up to 9 segments (as illustrated in Figure 3.1). It will then let you generate up to 46 ionospheric profiles within *each segment*! This gives you the ability to sharply increase the number of profiles generated over the 15,000 kilometer path from 46 to as much as 414 (46 profiles x 9 segments).

So let's see what happens if we use segmentation in our example. At the prompt asking for the distance along each bearing, let's specify a distance of 7,500 kilometers (we're splitting the 15,000 kilometer path into *two* segments of 7,500 kilometers each). When prompted for the number of profiles to build along the 7,500 kilometer path, we will specify the maximum allowed of 46. The last prompt presented asks you how many segments should be built. By specifying a value of 2, PROPLAB will build a total of two segments along each bearing specified, spanning a total distance of (2 segments x 7,500 kilometers) 15,000 kilometers. *However*, notice that within each segment we are creating 46 ionospheric profiles, thus decreasing the distance between ionospheric profiles from 326 kilometers to 163 kilometers (half the distance!). The resolution has therefore increased by a factor of *two*! By specifying a value of 3 segments (instead of two), PROPLAB would build *three* segments, each 7,500 kilometers in distance. Rays could therefore theoretically be traced out to a distance of (7,500 kilometers x 3 segments) 22,500 kilometers. However, in reality, this distance would be limited to 20,000 kilometers because PROPLAB's comprehensive ray-tracing engine will not trace beyond this distance.

By splitting up our 15,000 kilometer path into 9 segments containing 46 profiles each, we decrease the spacing between ionospheric profiles from 163 kilometers (for 2 segments) to 36 kilometers (15,000 km / 9 segments / 46 profiles-per-segment). This is the best PROPLAB can do and is far better than we probably really need because in most cases, ionospheric characteristics do not change appreciably over distances as small as 36 kilometers. Hence, interpolation will not introduce any appreciable inaccuracies in the traced rays.

PROPLAB saves each *segment* of ionospheric profiles to a separate disk file within the PROFDATA subdirectory that is created when you install PROPLAB. If you instruct PROPLAB to build 9 segments, it will save 9 separate files containing all of the ionospheric profiles for those segments.

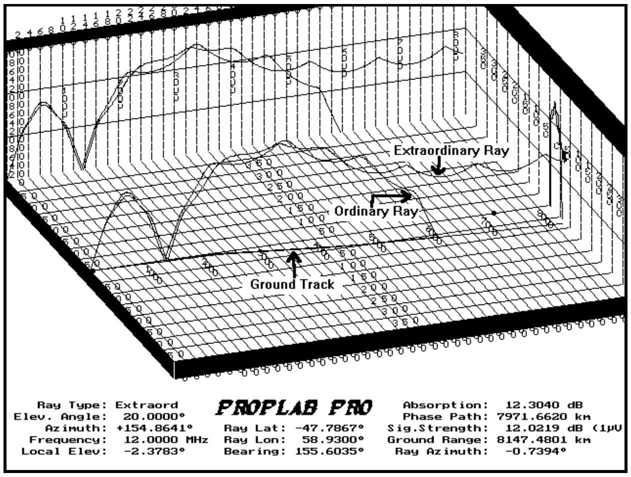
PROPLAB saves one file for every step in the bearing (or azimuth) that is used, as well. For instance, in our example where we built ionospheric profiles spanning a 10-degree range at steps of 1 degree each, PROPLAB would save 10 separate files to the PROFDATA subdirectory (one for the 95 degree bearing, another for the 96 degree bearing and so on until the 105th degree bearing was saved). By using a stepping rate of 0.1 degrees per bearing, the number of saved files increases to 100 (10 degree range / 0.1 degrees per bearing).

The amount of disk space consumed increases dramatically if you are not careful in your selection of parameters. The more profiles you build along each segment (up to a maximum of 46 profiles per segment), the greater the disk space will be. One profile per segment produces a small file size (less than about 10K bytes). Specifying 46 profiles per segment, however, requires nearly 152K bytes of disk space *per file*! Therefore, in the above examples, saving 9 segments containing 46 profiles across a 10-degree bearing range using 0.1 degree bearing steps could result in a profile database being created that approaches 136.8 *megabytes* ([10 degree span / 0.1 degree stepping rate] x 9 segments x 152K bytes per segment)! Systems with large hard-drives could conceivably handle this, but most likely this level of resolution is overkill unless you require highly accurate results with essentially zero inaccuracies. It would be far better to reduce the number of segments to 2 or 3. In most cases, a 0.1 degree bearing stepping rate is also overkill, particularly on shorter distances less than about 10,000 kilometers. A stepping rate of between 0.25 and 0.5 degrees should suffice for most instances. The amount of disk space required decreases substantially if we save 3 segments containing 46 profiles across a 10-degree bearing range using 0.1 degree bearing steps. In this case, the size decreases from 136.8 *MB* to only 9.1 megabytes. If the traced rays do not deviate very substantially from the great-circle paths, the bearing range could even be reduced from 10 degrees to 5 degrees, which would cut the required disk space in half again to only 4.56 megabytes. In many instances, particularly with segments less than about 8,000 kilometers, the number of profiles per segment can be reduced substantially without significantly affecting results.

So selecting wise parameters in suboption #21 of the Comprehensive Options menu will help you control the amount of disk space consumed when developing three dimensional profiles.

This discussion goes into relative detail regarding the way PROPLAB computes ionospheric profiles. If you do not understand the method, reread this section until you do. Failing that, experiment with PROPLAB. Nothing teaches better than hands-on experience. Keep in mind that PROPLAB PRO contains a useful context-sensitive help system. If any of the prompts are confusing or seem ambiguous, press the F1 key for more detailed descriptions.

3.4.1.4 Understanding the Three-Dimensional Grid



```
   Ray Type: Extraord                      Absorption:  12.3040 dB
Elev. Angle:  20.0000°                     Phase Path: 7971.6620 km
    Azimuth: +154.8641°  Ray Lat: -47.7867°  Sig.Strength:  12.0219 dB (1µV
  Frequency:  12.0000 MHz Ray Lon:  58.9300°  Ground Range: 8147.4801 km
 Local Elev:  -2.3783°   Bearing: 155.6035°   Ray Azimuth:  -0.7394°
```

The three-dimensional grid shown to the right was produced during a sample ray-tracing session using the comprehensive ray-tracing technique. It shows one ray entering the ionosphere and splitting into two component parts (the ordinary and extraordinary parts). Unlike the simple ray-tracing technique, the comprehensive ray-tracing technique draws a straight line from the transmitter to the location where the ray enters the ionosphere. The simple technique draws a smooth curve showing how the ray gradually bends upward because of the Earth's spherical shape. The comprehensive technique performs the same computations, but speeds up ray-tracings by simply plotting a straight line to the location where the ray penetrates into the ionosphere. This is why the base part of the ray paths may appear a bit discontinuous. It does not affect the accuracy of the tracings at all.

Notice how these two rays (the ordinary and extraordinary rays) each travel independent paths through the ionosphere. Notice also how the ordinary ray undergoes a chordal reflection over the equatorial region on its second hop before it returns to the ground. The extraordinary ray also experiences a chordal hop on its second hop. However, unlike the ordinary ray, the extraordinary ray becomes trapped between the E and F-layers in a process called "ducting". Ducting is quite common and can result in extremely long signal paths if the geometry is right. Signals that are ducted tend to have a "whispery" tone to them, but in many cases the signals remain quite intelligible.

The three dimensional grid shown above should be viewed as follows. Imagine the base of the grid (where the transmitter and receiver reside) forms the *inside* of a box with only two sides. In the above example, the far-side of the box forms the "altitude wall". This wall shows the altitude of the traced rays in the ionosphere. The right-side of the box forms the "lateral deviation wall" and shows you the extent to which rays may be deviated laterally (away from the great-circle path). The great-circle path itself is indicated by the line connecting the transmitter to the receiver. This line also forms the 0 (zero) kilometer lateral deviation line on the right-side of the box (the lateral deviation wall). The traced lines curving along the base of the grid indicates the true path the signals take through the ionosphere. In this case, it is obvious the traced rays are being deviated away from the great-circle path by ionospheric tilts and interactions with the Earths magnetic field.

All distances on the three-dimensional grid are labelled in kilometers. The distance toward the receiver is indicated by the multiple (fairly closely spaced) lines that travel along the base of the grid toward the receiver but perpendicular to the great-circle line. These lines are then mirrored up onto the altitude wall so it is easier to determine the distance of traced rays by examining the altitude of the ray in conjunction with the distance. The lateral deviation distances are displayed beside the lines which lie parallel to the great-circle line on the base grid. These lines (like the zero kilometer lateral deviation line which forms the great-circle) are mirrored onto the lateral deviation wall so that rays which diverge from the great-circle path can be more easily discerned and measured in distance from the great-circle line.

The key below the grid shows numerous statistics which will be of interest during the tracing of signals. The information displayed is explained below:

Ray Type: Gives the type of ray (ordinary or extraordinary) that is currently being traced. Ordinary rays are colored white. Extraordinary rays are colored yellow.

Elev. Angle: Defines the elevation (take-off) angle used by the transmitting antenna. A value of 0.00 degrees indicates PROPLAB is tracing a ray that was originally "shot" at the horizon.

Azimuth: Lists the azimuth that was used at the transmitter for the current ray being traced. A value of 0.00 degrees indicates PROPLAB is tracing a ray that was directed directly northward by the transmitter. It does not indicate the current azimuth of the ray (see the *bearing* below).

Frequency: Gives the frequency of the ray currently being traced in MHz.

Local Elev: This section defines the elevation of the wave-normal of the ray with respect to the horizontal. A value of zero degrees means the ray is travelling exactly horizontal. Positive values indicate the ray is travelling upward at the specified angle. Negative values indicate the ray is travelling downward toward the ground at the specified angle. This value is continually updated as the ray is traced through the ionosphere.

Ray Lat **and** ***Ray Lon***: These values identify the current geographical location of the ray being traced through the ionosphere. Positive latitudes represent northern hemispheres. Negative latitudes represent southern hemispheres. Longitudes are given in a direction measured west of Greenwich and never become negative. Therefore, values between 0 and 180 represent western longitudes and values between 180 and 360 represent eastern longitudes.

Bearing: Defines the current azimuthal bearing of the ray as measured from the transmitter. In other words, this value represents the bearing required for the ray to get from the transmitter to its current geographical location. It is constantly being updated and gives you a good idea of the extent to which non-great-circle deviations may be affecting the ray.

__Absorption__: PROPLAB integrates the ionospheric absorption equations at the same time it integrates the ray-tracing equations. It is therefore a ***__highly__*** accurate measure of the total ionospheric absorption encountered from the time the ray left the transmitter to the current ray location and far exceeds the accuracy of empirical absorption calculations performed by most other propagation programs.

__Phase Path__: This will likely only be used by those with a deeper knowledge of ionospheric radio propagation. It indicates the phase path of the ray and is constantly updated as the ray is traced.

__Sig.Strength__: This value is the computed signal strength of the ray currently being traced. It is only updated when the ray either penetrates the ionosphere or reaches (or is reflected) by the ground. It is given in units of dB (actually dBi or decibels above one microvolt). Positive values indicate "hearable" signals. Negative values refer to signals that have lost most if not all power to absorption, ground reflections, signal spreading, etc.

__Ground Range__: This value represents the ground range of the ray away from the transmitter and is computed as the great-circle distance of the ray from the transmitter. It does not represent the total *geometrical* distance (that is, the total distance the ray travels. For this, you must instruct PROPLAB to save ray-tracing results to the "RESULTS.OUT" text file. The geometrical distance figure is saved to this file along with other valuable parameters such as group path and polarization.

__Ray Azimuth__: This value defines the extent to which the currently traced ray is deviating from the great-circle path (in degrees). A value of 0.00 degrees means the signal is precisely following the great-circle path.

With this information at your disposal, interpreting the results of three-dimensional ray-tracings should be easier and more enjoyable.

3.4.1.5 The Text File Ray-Tracing Results

PROPLAB PRO Version 2.0 comes equipped with an option that will save detailed ray-tracing information to a textual disk file named "RESULTS.OUT". The information saved to this file includes the current altitude of the ray, ground range, phase path, group path, geometrical path distance (that is, the total distance travelled by the ray), absorption, doppler (if any), polarization (both real and imaginary parts), the local elevation angle of the wave-normal component of the ray with the horizontal, the elevation angle of the ray as measured with respect the transmitter, the azimuthal deviation of the ray away from the great-circle path, and the current azimuth from the transmitter to the ray location. This information almost completely describes the characteristics of the traced rays.

Caution should be exercised when saving data to the text file. The size of the file can quickly increase depending on the type of ray-tracing being performed. A single long-distance traced ray can result in a text file exceeding 50K bytes. Complete ray-tracing sessions saved to disk may end up exhausting disk space. However, it is the only method that provides complete snapshots of traced rays as they are travelling through the ionosphere.

3.4.2 Computing MUFs between any two points

This option makes use of the *simple* ray-tracing technique only. Automatic computation of the MUF using the comprehensive ray-tracing technique is currently beyond the capability of PROPLAB as it would require three-dimensional homing capabilities (an extremely difficult and time-consuming process), particularly if done in three dimensions. Perhaps it will be attempted in future versions of PROPLAB.

The second option of the Main Menu lets you compute MUFs for any distance. You are requested to enter the latitude and longitude of the transmitter and receiver. If this has already been set, simply press ENTER to use those values. PROPLAB next asks you to type in the distance (in kilometers) for the MUF. If you press ENTER at this prompt, PROPLAB will automatically calculate the MUF for the distance between the transmitter and receiver. If you specify a distance, the MUF will be computed at that distance on a bearing (azimuth) towards the destination. PROPLAB will always compute the MUF for the shortest path between the two points.

PROPLAB rigorously calculates the MUF. That is, it searches for a skip distance that coincides with the desired MUF distance and selects the maximum frequency at that distance. This is a much more complicated procedure than most algorithms used in simpler propagation programs. Those programs basically compute the MUF using empirical algorithms that may assume simplified ionospheric parameters. For example, some routines used by other programs are able to rapidly compute the MUF by referencing very simple models of ionospheric layers. Others attempt to take into consideration effects of geomagnetic activity. In many cases, the results of these programs are fairly accurate, but may completely fail during geomagnetic storms or other phenomena.

PROPLAB makes only very few simplifications to help speed up the process of finding MUFs. It will only consider two control points on the path between the transmitter and receiver. The control points are carefully chosen and a respectable amount of time is consumed simply searching for these control points. The MUF for each of these control points is then computed. The lower of the two MUF's for the two control points is the MUF for the desired distance. This method of computing MUF's is valid and accurate for a wide range of conditions and paths.

During the MUF computations, PROPLAB uses a realistic ionospheric electron density profile for each control point and traces appropriate rays through these profiles until the MUF is found. When PROPLAB numerically traces through the ionosphere for these control points, it does so using steps in distance that are approximately 2.5 times larger than those that are associated with the "Ray Tracing Speed" (see Section 3.3.3). This significantly speeds up calculations, but may degrade the accuracy of the results slightly. To increase the accuracy of the MUF computations, decrease the ray tracing speed by decreasing the "Ray Tracing Speed" value in the Options Menu (Section 3.3.3).

After PROPLAB has found the MUF, the frequency is displayed along with the transmission elevation angle required. Using the computed frequency and a directional antenna oriented at the appropriate azimuth and the required angle of elevation, you should be able to transmit at the maximum usable frequency to the desired receiver location.

You can verify the computed MUF by ray tracing through the ionosphere at the given frequency and sweeping elevation angles around the required angle given. This is what was done to produce the results given in Figure 2.5. More accurate results can be obtained if you ray trace signals by sweeping the elevation angles using the three-dimensional comprehensive ray-tracing technique. You may be surprised how different the signals behave when effects of the Earth's magnetic field and ionospheric tilts are considered.

PROPLAB also gives you the option of rigorously computing the FOT, or Frequency of Optimum Transmission. Normally, the FOT is considered to be 85% of the MUF (0.85 x MUF). Our definition of the rigorously computed FOT differs. Our definition requires that at least 85% of the radiated transmitter energy is reflected by the ionosphere. The remaining 15% is lost to space because of ionospheric penetration. In most cases the rigorously computed FOT will be lower than the MUF. But in many situations, you may see rigorously computed FOTs that actually exceed the MUF. For example, the MUF may be computed at 23 MHz, while the rigorously computed FOT is computed at 26 MHz. This simply tells you that the ionosphere will reflect 85% of the power at 26 MHz. It is essentially independent of the MUF.

3.4.3 Setting up Regions of Sporadic-E

Since the comprehensive ray-tracing technique does not take sporadic-E into consideration, this section only applies to the simple ray-tracing technique.

The third option of the main menu gives you the ability to define regions of sporadic-E. For this function to operate properly, you will need a Plate Carree map projection available in your map library. If one is not available, PROPLAB will notify you and return you to the main menu. To create a Plate Carree map, use the utility "MAKEMAP.EXE".

To define regions of sporadic-E, you will need a mouse hooked up to your computer.

When first selecting this option, you will be asked whether you want to define the locations of the transmitter and receiver (by pressing "X") or regions of sporadic-E (by pressing "S"). Press "S" and hit ENTER to define regions of sporadic-E.

If you have a Plate Carree map in your map library, the software will ask you if you want to use the map present in the map library. If you have more than one Plate Carree map projection in your map library, you can select the map you would like to use by skipping the unwanted maps.

After you have selected the desired map, PROPLAB begins computing the position of the auroral ovals and displays the ovals superimposed on the desired map, along with the position of the grayline, Sun, and the current signal path defined by the transmitter and receiver locations. In addition, regions of sporadic-E which you may have used in previous runs are displayed on-screen. Altogether, a great deal of information is made available on-screen. You can determine, for instance, the proximity of the signal path to the auroral zones, where (if at all) the signal crosses into the auroral zones, whether the signal spends any time (and how much time) in daylight or darkness, and even whether the signal crosses regions of sporadic-E. With this information in-hand, you can begin defining regions of sporadic-E with your mouse.

Moving the mouse moves the mouse cursor on the screen. Regions of sporadic-E are defined by marking rectangular regions with the mouse cursor. This is done by positioning the mouse cursor to the upper-left corner of the desired sporadic-E region and clicking on the LEFT mouse button. A corner pointer will be placed on the screen where the left button was clicked. Now move your mouse over to the area where the bottom right corner of the sporadic-E region exists and click on the RIGHT mouse button. This defines the rectangular sporadic-E region.

PROPLAB next asks you to type in the critical frequency of the sporadic-E region. The value you type here determines how intense the ionization is within the defined rectangular region. The ionization, in turn, determines the extent of signal refraction and reflection which can occur in that region. Sporadic-E can vary over wide ranges, from critical frequencies of only about 1.5 or 2.0 MHz to critical frequencies as high as 30 MHz under rare conditions. In most cases, sporadic-E varies between approximately 2 MHz and 10 MHz with an average maximum nighttime critical frequency of about 2 to 5 MHz.

Due to the unpredictable nature of sporadic-E, it is impossible to determine for certain what level of sporadic-E exists at a specific period of time. The only definite way to measure the critical frequencies of sporadic-E are with vertical ionosondes. But such instrumentation is usually out of reach of most amateurs and may require special class licenses to operate on the HF bands, since they can create interference with other broadcasters.

Many ionospheric sounding stations report critical sporadic-E frequencies to the World Warning Agency (WWA) in Boulder Colorado. The WWA then provides this information in a coded format to other organizations. Part of the responsibility of the Solar Terrestrial Dispatch is to decode this data and disseminate it to the general public, researchers, and other scientific organizations. The daily summary of ionospheric data can be obtained from the STD computer BBS at 403-756-3008 in the Ionospheric Data submenu. Old data is archived into files having the format "iono-xxx.[zip]" where "xxx" is replaced with the first three letters of the month desired (ex. "iono-nov.zip"). These archived files are available in the directories "pub/solar/1991", "pub/solar/1992", etc. These daily ionospheric data reports contain critical F2-layer frequencies, critical sporadic-E frequencies, and much more for many stations around the world. Using these reports, it may be possible to determine exactly what level of sporadic-E may have been influencing your region (or your signal path).

Type the critical frequency of the sporadic-E layer (in MHz) at the prompt requesting this information, being guided by the data available from the daily ionospheric reports, or by estimating the values according to the guidance given in the preceding paragraphs. Keep in mind that sporadic-E is very often associated with the auroral zones. During active or storm periods of geomagnetic activity, the auroral zones may be filled with regions of sporadic-E. The equatorial regions are also areas where frequent sporadic-E can occur, particularly during the daytime hours. Middle latitudes observe sporadic-E more during the equinoxes and geomagnetic storms, but are not restricted to these times. Sporadic-E can occur almost anytime and anywhere. Areas within and poleward of the auroral zones are often associated with regions of enhanced E-layer ionization corresponding to critical E-layer frequencies of about 1.5 MHz. High latitude regions may observe night-time periods of E-layer critical frequencies of this magnitude on a near-daily basis. During the night, the critical frequency of the E-layer usually drops to about 0.4 MHz. Critical frequencies of 1.5 MHz are sufficient to affect some low-band frequencies.

After the critical frequency of the defined rectangular sporadic-E region has been entered, the map is redrawn with the newly defined region of sporadic-E superimposed on the map, along with its associated critical frequency.

To select another region, move the mouse to the desired location and click on the LEFT mouse button again. If you decide you do not want to define a region at the location marked by the left mouse button, press the left mouse button a second time to deselect the marked region. To remove a defined and superimposed sporadic-E region, move the mouse cursor so that it lies somewhere overtop of the displayed sporadic-E region and click the RIGHT mouse button. This will remove any defined sporadic-E region.

Sporadic-E regions can be superimposed on other regions of sporadic-E.

If you do not have a mouse available, the rectangular geographical coordinates of the sporadic-E regions can be inserted into the text file "PROPLAB.ES" in the following format: "Top-Left-Latitude,Top-Left-Longitude,Bottom-Right-Latitude,Bottom-Right-Longitude,Critical-Frequency". The quoted section must reside on one line as follows:

```
+45.32,105.4,+40.67,85.7,6.0
```

In this example, the top-left geographical coordinates of the rectangular sporadic-E region are +45.32 degrees north latitude and 105.4 degrees west longitude. Similarly, the bottom-right geographical coordinates are +40.67 degrees latitude and 85.7 degrees longitude. The critical frequency of this region of sporadic-E is 6.0 MHz.

With or without a mouse, you can define up to 99 individual regions of sporadic-E. There is no limit on the geographical spatial extent of each individual region. They can be as large or as small as you like. It may be useful to remember that most regions of sporadic-E are fairly small in spatial extent, covering an area perhaps several hundred kilometers in extent. This is generally true except perhaps in the auroral zones where Es may be more widespread and cover areas many hundreds of kilometers in extent. Polar regions of Es usually exist in bands or ribbons extending across the polar cap in roughly the direction of the Sun.

To quit defining regions of sporadic-E, press the ESCape key on your keyboard. The regions of sporadic-E that you defined (or edited/removed) will be saved to disk under the text file "PROPLAB.ES".

You can save screen images while in this mode by pressing the "G", "P", or "S" keys. These functions save screen images in GIF image formats, PostScript-compatible formats, or a special format as described below, respectively. Pressing "S" saves screen images in a special format. Such saved screen images can be used in other functions of PROPLAB to (for example) superimpose contours of ionospheric characteristics, or generate broadcast coverage maps. Maps of different types can in this way be combined into a single image. For example, the screen image saved while in this mode provides positional information of the auroral zones, the sunrise/sunset grayline, the position of the Sun, the signal path, and regions of sporadic-E. Using this "S"ave function, you can combine this map with contours of maximum usable frequencies, and/or contours of maximum F2-layer heights, and/or contours of solar zenith angle, and/or with broadcast coverage maps, etc. The end-result could be a screen image loaded with invaluable information.

3.4.4 Setting up Transmitter and Receiver Locations

The third option of PROPLAB's Main Menu gives you the ability to define regions of sporadic-E or transmitter/receiver geographical positions. Select the latter by pressing "X" followed by ENTER. Setting up the transmitter and receiver locations has been described in detail in Section 3.3.2. Refer to that section for more information.

After you have defined the transmitter and receiver locations, press the ESCape key on your keyboard to return to the PROPLAB Main Menu.

3.4.5 Plotting Electron Density Profiles

The fourth option of the Main Menu will plot electron density profiles for any SINGLE-HOP path *MIDPOINT* specified. The midpoint is defined as that point that lies half-way between the transmitter and receiver on the great-circle path. If the great-circle distance exceeds 4,000 kilometers, only the profile for the midpoint of the FIRST HOP is used. This is useful for determining ionospheric conditions at any path midpoint. To determine conditions at the transmitter geographical location, set the receiver geographical position to the transmitter position so the path midpoint lies over the transmitter location. For example, if the transmitter was located at 40N 105W and the receiver was located at 45N 75W, to determine the ionospheric electron density profile at the transmitter, use the Options Menu to set the receiver geographical coordinates to 40N 105W. The midpoint obviously therefore must also be 40N 105W, which is the desired profile location. Similarly, to see the profile at the receiver location, set the transmitter location equal to the receiver location. In this case, the transmitter and receiver geographical positions would be set to 45N 75W respectively.

PROPLAB will plot the electron density profile for any geographical location, any time of day, and any date, up to an altitude of 1,000 kilometers. When the geomagnetic A-index is equal to 5, this profile exactly coincides with the output of the International Reference Ionosphere. For larger values of geomagnetic activity, the electron density profile may be altered according to the strength of magnetic activity, the geographical position of the profile, and other known influencing parameters.

Electron density profiles provide you with a wealth of information at a glance. For example, you can determine exactly at what height the maximum electron density occurs. You can determine the magnitude of E-layer ionization and learn how the profile changes from daytime conditions to night-time conditions. You can examine approximate effects of geomagnetic activity on the profile characteristics, and can determine at what altitude ionization begins in the ionosphere for daytime and nighttime conditions. As well, if sporadic-E is present, you can see the spike in electron density that exists in the narrow region where sporadic-E exists.

This is a useful function for determining the overall internal "shape" of the ionosphere at any given time, date, or level of geophysical activity for any geographical position.

3.4.6 Displaying Ionospheric Profile Statistics

The fifth, sixth, and eighth through eleventh options of the Main Menu will be covered in detail shortly. But first, we will examine what the seventh option of the Main Menu does. Selecting this option will display ionospheric profile statistics on-screen at the midpoint between the transmitter and receiver (just as described in the previous section).

After the ionospheric electron density profile has been computed and adjusted (if necessary), information describing the properties of the ionosphere are displayed in a textual format on-screen.

At the top of the screen, the UTC date and time are given, along with the transmitter geographical position (given as the "Origin"). The next line lists the sunspot number and geomagnetic A-index values that were used to generate the profile statistics, as well as the geographical path midpoint position. This is the location where the profile statistics are valid.

The next four lines define the characteristics of the F2 layer. The first line lists the critical frequency of the F2 layer for both quiet (A-index of 5) and disturbed or "dynamic" times. The dynamic value is an estimated critical frequency determined after taking geomagnetic activity, magnetic latitude and longitude, etc, into consideration. The next line lists the ionospheric M-factor for distances of 3,000 kilometers during quiet conditions. The M-factor is the ratio between the maximum usable frequency for a distance of 3,000 kilometers and the critical frequency. Using this value and the quiet-time F2-layer critical frequency value, you can determine the MUF by multiplying the two values together. For example, if the critical F2-layer frequency was 4.436 MHz and the M-factor was 3.13, the MUF for a distance of 3,000 kilometers (also written as "MUF(3000)") would be: 4.436 x 3.13 = 13.885 MHz. For distances less than or greater than 3,000 kilometers, it is necessary to perform interpolation or extrapolation on the data. However, this is unnecessary since the MUF for given distances can be directly determined through the use of the second Main Menu option (Compute MUFs). The maximum F2-layer height is listed on the next line. The height where the electron density for the F2-layer reaches a maximum is known as the maximum F2-layer height, or hmF2. The value for quiet-time and dynamic conditions is given. The dynamic value is a quick estimate and may be more accurately determined by producing an electron density plot for the same region. You will notice that as the level of geomagnetic activity increases, the height of maximum electron density also tends to increase. The final of these four F2-descriptive lines gives you the maximum electron density of the F2-layer for both quiet and dynamic conditions. These values will exactly coincide with plotted electron density profiles.

The next three lines are for F1-layer statistics. The first of these three lines defines the critical frequency of the F1-layer, if it is present. If the F2-layer ionization overlays the F1-layer maximum, then the F1-layer critical frequency is invalid and is listed here as zero. If the F1-layer maximum is not influenced by the F2-layer, then the critical frequency is listed here in MHz. The value given will be similar for both quiet and dynamic conditions. Geomagnetic activity has a heavier impact on the F2-layer characteristics. The maximum electron density of the F1-layer is listed last, if the F1-layer maximum can be separated from the lower-side of the F2-layer. If the F1-layer maximum cannot be differentiated, the density value listed on this line is given as zero.

The next six lines displayed define the characteristics of the E and D regions of the ionosphere - three lines for each region. The first three lines define the E-region critical frequency, the E-region maximum height of electron density, and the associated E-region maximum electron density. You will notice that the maximum height of electron density of the E-region is generally fixed at 105 kilometers. The three lines devoted to the D-region are the same as those for the E-region. Specifically, the first line defines the D-layer critical frequency (which you will notice is significantly smaller than the critical frequencies of the other layers). The final two lines list the height of the maximum D-region electron density, and the maximum electron density of the D-region itself.

The final four lines of the display show related statistical quantities that are fairly important for determining the ionospheric profile. The first line lists the solar zenith angle for the time, date, and geographical position of the profile. The solar zenith angle is the angle of the Sun measured from the zenith (straight up). It is different from the solar elevation angle (which is also listed here) in that the solar elevation angle is the angle measured from the horizon to the Sun in the sky. The solar zenith angle is measured from the zenith instead of the horizon. Therefore, a solar zenith angle of 90 degrees corresponds to a solar elevation angle of zero degrees, which represents the position of the sun directly on the horizon 90 degrees away from the zenith. Likewise, a solar zenith angle of zero degrees corresponds to a solar elevation angle of 90 degrees and represents the position of the sun directly overhead at the zenith. The second line gives the solar declination angle, or the angle above or below the solar equator where the Sun appears directly overhead at 12 noon. Because of the orbit of the Earth around the Sun, this angle varies by about +/- 23 degrees. At the seasonal equinoxes (spring and fall), the solar declination angle is about zero degrees. Therefore, during these times, the Sun would appear directly overhead at noon, over the equator. The third line gives you the magnetic latitude and longitude of the geographical position used in the profile statistics. The geographical position of the profile statistics is given in the second line of the display after the " Profile Location". The final line of this display shows you the magnetic DIP (or inclination) angle at the current geographical profile location.

To return to the PROPLAB Main Menu, press the ENTER key.

3.4.7 Quitting PROPLAB and returning to DOS

To leave PROPLAB's Main Menu and exit to the DOS prompt, simply select the twelfth option of the Main Menu or press the ESCape key.

SECTION 4 - GLOBAL IONOSPHERIC MAPS

A substantial amount of PROPLAB's power lies in its ability to generate practically any type of map for almost every type of ionospheric parameter relevant to radio communications. The maps resemble weather-type maps and use complex contouring algorithms to produce contours of equal values. By selecting the fifth option of PROPLAB's Main Menu, you gain access to this large base of power. This section will describe the available types of maps that can be generated and how they can be used.

You retain full control over how you want the maps generated, right down to the color for the contour lines.

All of the different maps require you to enter specific common information: the date, time, sunspot number, geomagnetic A-index (or press ENTER if not available), sunspot number, map resolution level, type of map projection to use, type of map to generate, contour specifications, ionospheric model to use, and the contour color to use.

The date, time, sunspot number, geomagnetic A-index, and type of map to generate are self-explanatory inputs and need no further discussion. The others need to be explained in slightly greater detail before reliable use of these powerful functions can be expected.

For each map generated, you will be asked to select a map resolution level. This determines how spatially accurate the map is for the given date and time, etc. There are five different resolution levels that can be selected. The lowest resolution level produces maps much quicker than higher resolution levels, but the spatial accuracy of the map may be lacking. In other words, some features that may be present might not be shown in the lower resolution maps.

The resolution level varies according to the type of map projection you select. For example, the spatial resolution and accuracy of a global Lambert map projection can be approximately doubled if a polar-map projection (such as an orthographic projection) is used. Why? Simply because a polar-map projection includes only half the surface area of a global Lambert projection, which permits PROPLAB to compute ionospheric parameters for more of the available surface area. A polar projection only includes those geographical areas that are either north or south of the equator. A Lambert projection includes both the north and south hemispheres and hence twice the surface area. Ionospheric profiles must therefore be computed for larger spatial distances when larger spatial areas are included. For greatest spatial resolution, select the highest available resolution levels and use polar map projections.

PROPLAB gives you full control over how contours are to be labelled. One of the common inputs required defines how you want contours to be labelled. The default is to label all contour lines. You can also instruct PROPLAB to label only every Nth contour, only the lowest and highest valued contours, or not to label any contours at all. Usually, you will want to label all contours, although in cases where the labelling from contours may overlap one another, it may be useful to label only every other contour, etc. The choice is yours.

PROPLAB also asks you for the minimum value to contour, the maximum value to contour, and the stepping rate for contouring between the minimum and maximum values. For example, to create a global map of MUFs with contours defining the 5, 10, 15, 20, 25, and 30 MHz MUF zones, you would specify a minimum contour value of 5, a maximum value of 30, and a stepping rate of 5 (MHz). By pressing ENTER at each of these prompts, the software automatically contours from the minimum computed value to the maximum computed value at step increments that would result in maximum contour resolution. In other words, by default, PROPLAB will produce maps with the greatest number of possible contours. PROPLAB will allow up to 25 individual contour lines per generated map.

PROPLAB also gives you the ability to define what color to use when drawing contours. You can select one of 15 different colors. The default color is light cyan.

If you have previously saved a map with information on it such as the sunrise/sunset grayline, location of the auroral zones, signal path, etc, you can inform PROPLAB to use a previously saved map and superimpose all contours on that map. This powerful feature lets you integrate maps of different types and superimpose contours on those maps. For example, by pressing the "S" (for Save") key while editing sporadic-E regions or graphically setting new transmitter and receiver points, you can save the screen image to disk and later use that same map projection to superimpose contours of ionospheric quantities.

While PROPLAB is drawing contours, a small box will flash red and white at the top right-hand corner of the screen. This is used to tell you that PROPLAB is busy thinking. You can abort the drawing process anytime by pressing the ESCape key. When PROPLAB has finished drawing contours, the box disappears and a label identifying the type of map completed is printed on the screen. You can then press the "S" key to save the screen image for integration in other functions or for superimposing other contours on the same map. You can also press the "G" key to save a copy of the screen image as a GIF image file. Or, you can press the "P" key to save the screen image in a PostScript-compatible file for printing to a laser printer.

4.1 Global Maps of Critical F2-Layer Frequencies

These very useful maps provide you with instantaneous information regarding world-wide critical F2-layer frequencies. A sample map is shown in Figure 4.1.

This Figure was produced by PROPLABs "CONTOUR.EXE" utility (invoked by Main Menu Option #5) and is exceptionally valuable for radio communicators. It shows you the critical frequencies of the F2-layer throughout the world, at a specific date and time, level of geomagnetic activity, and sunspot number. Using the information from this map, it is possible to determine where horizontal gradients exist in the electron density profile that might cause non-great-circle propagation. It is also used to determine maximum usable frequencies, the general state of the ionosphere, etc.

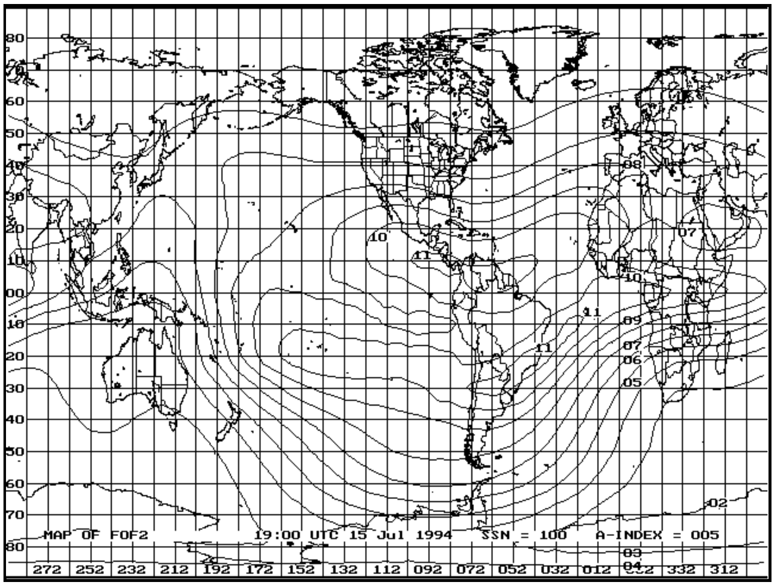


Figure 4.1: *Global Map of Critical F2-Layer Frequencies*

Recall that the critical F2-layer frequency is the maximum frequency that can be reflected vertically from the F2-layer. Since the F2-layer is usually the main layer responsible for ionospheric signal refraction, it is sometimes called the vertical penetration frequency because on frequencies higher than the F2-layer critical frequency, vertically propagated signals will penetrate the ionosphere.

There are several features of interest to point out here. Notice the high critical frequencies near the equatorial region. These enhanced foF2 values are known as the equatorial anomaly. They occur within approximately +/- 20 degrees of the *magnetic* equator, not the geographic equator. This is why the increased values tend to drift into South America away from the geographical equator - the magnetic equator dips below the geographical equator and reaches a maximum difference near South America.

Regions where the sun is rising or setting produce pronounced changes in the electron density profile that are easily discerned in the sample foF2 map given in Figure 4.1 for 19:00 UTC. At this time, it is near noon for the North American region and critical F2-layer frequencies (and hence F2-layer ionization levels) are at a maximum for the day. Toward the west (toward the sunrise sector) the critical F2-layer frequencies begin decreasing. Critical F2-layer frequency gradients are strongest near eastern Australia where the sun is rising and the F2-layer is being rapidly ionized. Gradients can be determined by examining how close the foF2 contours come to each other. In general, the stronger the gradient, the less stable the ionosphere is and the more likely signals will experience non-great-circle propagation through resulting horizontal tilts in the electron density gradient. PROPLAB will not take horizontal tilts into consideration for computing possible non-great-circle paths. Future versions of PROPLAB may, however.

Radio signals which are propagating through the ionosphere are most stable where the contour gradients are weakest (or farthest apart), OR when signals use paths that FOLLOW the gradient contours. The latter may require further explanation. Signals that pass through high-gradient regions are more susceptible to non-great-circle propagation and may experience less stable conditions. However, these effects can be minimized if paths are chosen that follow (as closely as possible) the contour lines in high-gradient zones. For example, on transmissions from eastern Australia to Mexico, the signal path crosses the foF2 contours at almost perpendicular angles. In other words, the signal path goes AGAINST the gradient of the contours and is more likely to experience non-great-circle propagation and instabilities. Under these conditions, PROPLAB may be less accurate than usual, particularly on sunrise-crossing circuits. On the other hand, a signal path from eastern Australia to the southern tip of South America more closely follows the foF2 contours and GO WITH THE GRADIENTS. For this signal path, greater signal stability and less non-great-circle propagation would likely be observed. It is interesting to note that in this last signal path, the signal is essentially a "grayline signal", or one which follows closely along the sunrise-sunset terminator.

Maps produced with geomagnetic A-index levels less than or equal to 5 can be converted to monthly median maps if the sunspot number or solar flux value used is the average value for the last 12-months. By offsetting the geomagnetic A-index or sunspot number, it is possible to adjust the maps for conditions that may more closely represent observed conditions. In general, the geomagnetic A-index for the current UTC day as well as the sunspot number or solar flux value averaged over the last week or two, are sufficiently accurate inputs to model approximate observed conditions. It must be remembered that daily maps of foF2 may differ markedly from those produced here, since the ionosphere is still a highly unpredictable region of our atmosphere.

4.2 Global Maps of Ionospheric M-Factors

M-factors were discussed previously and represent the ratio between the maximum usable frequency for specific distances and the critical F2-layer frequency. For example, an M-factor for a distance of 3,000 kilometers would be computed by dividing the MUF for a path distance of 3,000 kilometers by the critical frequency of the F2-layer at the midpoint of that path. Numerically it is defined as:

$$M(3000)F2 = MUF(3000) / foF2$$

From this, if we know the critical F2-layer frequency (from an ionogram or station report), we can determine the MUF for a distance of 3,000 kilometers by multiplying the critical F2-layer frequency (foF2) by the M-factor for the same distance.

M-factors are therefore ratios of two ionospheric quantities. Producing global ionospheric maps of these factors can help determine how the MUF and foF2 are related. They can also be used together with maps of foF2 to compute MUFs for any part of the world.

4.3 Global Maps of Maximum Usable Frequencies

Out of all of the global maps produced by PROPLAB, these maps will perhaps be the most heavily used. For this reason, it is important that the maps be interpreted correctly and wisely. The following discussion uses the sample maximum usable frequency map in Figure 4.2.

This figure was produced for the same date, time, sunspot number, and level of geomagnetic activity as was used in Figure 4.1. They can be directly compared. The similarities are obvious. Maximum usable frequencies occur in the same regions as maximum F2-layer frequencies shown in Figure 4.1. Similarly, maximum contour gradients occur where the sun is either rising or setting. The most pronounced and easily defined is the sunrise sector. This is because the F2-layer electron density (and hence critical frequency) decreases slower during sunset than it increases during sunrise. In other words, the critical frequency changes more abruptly and systematically during sunrise than it does during sunset. Higher F2-layer critical frequencies will produce correspondingly higher MUFs for given distances, since the increased F2-layer ionization will reflect signals with higher frequencies. The map in Figure 4.2 shows MUFs in MHz for a path distance of 3,000 kilometers.

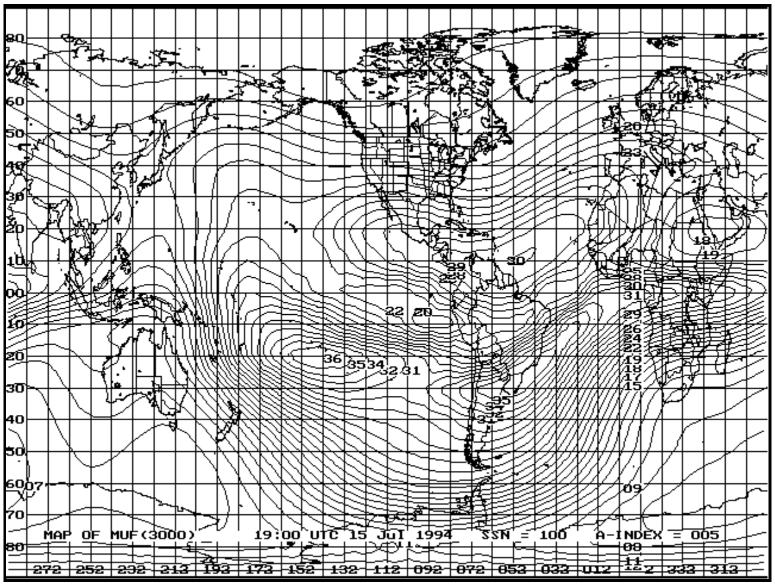


Figure 4.2: *Global Map of MUFs for 3,000 kilometers*

When instructing PROPLAB to produce global maps of MUF, you will be asked what distance to compute MUFs. The default is 3,000 kilometers. Most of the critical parameters for 3,000 kilometer MUFs have been precalculated. Producing default 3,000 kilometer MUF maps are therefore significantly faster than producing maps of different path lengths. Specifying paths of different lengths will force PROPLAB to rigorously compute MUFs for those distances by quickly ray-tracing through the ionosphere until the MUF for the given distance is found. This can be a time-consuming process, particularly on slower computers or if high map resolution levels are chosen. However, the results can be very informative and helpful.

It is important to understand how to correctly interpret MUF maps. To help us in this regard, let's examine how to correctly interpret the results of the map in Figure 4.2. Since this map shows the MUF for a distance of 3,000 kilometers, each point on the map is the MIDPOINT of a 3,000 kilometer path. For example, this map shows that South Africa has an MUF of 9 MHz for a distance of 3,000 kilometers. Therefore, if the MIDPOINT of your 3,000 km signal path passed over South Africa, you could expect to see an MUF of 9 MHz. Phrased a little differently, the MUF for a transmitter situated 1,500 kilometers (the path midpoint) away from South Africa would be 9 MHz if the signal passed over South Africa. This map would not apply for signals with greater or smaller path distances. It only applies for signals that travel 3,000 kilometers in ground distance.

This is exceptionally useful information and can help you determine optimum frequencies to use throughout the day for specific paths. It can also help you determine how long you can expect MUFs to remain above a specific frequency before MUF failure occurs. Notice that the smallest maximum frequencies occur during the nighttime and early morning hours, while the highest MUFs occur when the Sun is high in the sky near local noon. And as was explained with the foF2 maps, the highest gradients in MUF occur near sunrise, near the equatorial anomaly, and near sunset.

Over time, you will gain experience in using and applying these maps and will begin to learn how the ionosphere responds to the seasons, and even events such as geomagnetic storms. For example, MUFs may increase over the equatorial regions during geomagnetic storms, while decreasing substantially as the latitude is increased.

4.4 Global Maps of the Height Maximum of the F2-Layer

The maximum height of the F2 layer is a critical parameter that can strongly influence the distance related to a given maximum usable frequency. For example, if the MUF over the U.S. is fixed at 25 MHz for a distance of 3,000 kilometers, increasing the height of maximum electron density in the F2-layer would increase the distance for which this MUF applied. It may also increase the actual MUF. Decreasing the height maximum of the F2 layer (also known as the hmF2) would decrease the distance for which the MUF applied, and may also decrease the actual MUF.

Gradients in hmF2 can also change the path of a signal from one which follows the great-circle to one which deviates therefrom. Using paths that are both stable in critical frequency and stable in hmF2 usually give reliable and often strong signals. These are the paths which should be sought if communication reliability desired. If reliability is not as significant as MUF, then greater emphasis should be given to maps of maximum usable frequencies.

The height maximum of the F2-layer responds rapidly to changes in geomagnetic activity. Usually, the hmF2 increases as geomagnetic activity increases over the middle and high latitudes, since heating in the lower portion of the F2 layer erodes the ionization of that portion of the ionosphere and causes the maximum height of the electron density to increase. This may sound good from the point of view of increasing transmittable distances, however increases in geomagnetic activity are also accompanied by an attended decrease in F2-layer electron density (and hence critical frequencies) for the same reason as given above. This reduces the MUF over all affected regions. As it turns out, the reduction in foF2 is usually more important than increases in hmF2. And since any increase in hmF2 is usually accompanied by a decrease in foF2, any positive effects of increasing hmF2 are nullified.

4.5 Generating Maps of Critical E-Layer Frequencies

The critical frequency of the E-layer (or foE) is heavily dependent on the location of the Sun. For high solar elevation angles (or low solar zenith angles), the critical frequency of the E-layer reaches a maximum of between 3 to 4 MHz. That is, the frequency which would cause a vertically propagated signal to penetrate the E-layer would be between 3 and 4 MHz if the Sun were high in the sky. As the Sun drops toward the horizon, critical frequencies drop. After the Sun sets, ionization in the E-layer abruptly ends and critical frequencies fall even further. Minimum critical frequencies are observed around local midnight with foE values of about 0.4 MHz.

It is important to keep in mind that foE is dependent upon sporadic-E and enhanced nighttime E-layer ionization (perhaps caused by auroral electron precipitation, etc). Sporadic-E can increase foE by many times. For example, normal nighttime foE is around 0.4 MHz. A 5 MHz sporadic-E critical frequency would increase the nighttime foE value for affected regions to 5 MHz, which is a factor of 12.5 times greater than the normal nighttime foE value. These contoured maps of critical E-layer frequencies do not take these sporadic phenomenon into consideration, even if they are identified with PROPLAB as regions of sporadic-E. Only the regular non-deviative foE values are used in these plots.

4.6 Producing Maps of Solar Zenith Angles

These types of maps are exceptionally valuable when determining possible effects of solar flares on signal paths. Maps of solar zenith angles show the elevation angle of the Sun away from the zenith, or the point straight up overhead. A solar zenith angle of zero degrees corresponds to the point exactly straight up overhead. A solar zenith angle of 45 degrees corresponds to a point half-way between the horizon and the zenith. Similarly, a solar zenith angle of 90 degrees corresponds to a point directly on the flat horizon. Solar zenith angles of 90 degrees therefore denote areas of the world that are undergoing either sunrise or sunset. Solar zenith angles greater than 90 degrees denote areas of the Earth that are in darkness or twilight. Astronomical twilight typically ends (or begins) when the sun reaches a solar zenith angle of about 102 degrees (or about 12 degrees below the horizon).

During solar flare activity, maps of solar zenith angle are of primary importance for determining what areas of the world may be experiencing short wave fadeouts (or SWFs). A short wave fadeout is a period of time when shortwave (HF) signals suddenly (or gradually) fade out and disappear. As flares increase in magnitude, frequencies which can be affected by the activity increase. For example, a magnitude M1.0 flare may produce a SWF affecting frequencies up to 7 MHz. Compare this with a magnitude X1.0 flare, which may produce an intense SWF affecting frequencies as high as 15 or 20 MHz - effectively wiping out communications on most HF bands.

The extent to which flares affect communications depends on the solar zenith angle. Low solar zenith angles (or times when the Sun is high in the sky) result in the strongest SWFs and affect frequencies higher than at any other location on the Earth. As the solar zenith angle increases toward sunset or sunrise conditions, the effects of flares decreases. For solar zenith angles greater than 90 degrees (when the Sun is below the horizon), flares do not have any significant adverse effects on signal absorption, since the ionizing radiation is not impinging on the ionosphere when the Sun is not in the sky.

For these reasons, you can utilize the maps of solar zenith angles to determine where the strongest SWFs may be observed.

4.7 Producing Maps of Magnetic DIP Angles

PROPLAB will produce maps of magnetic DIP (or angles of inclination). Since many parameters in radio propagation are dependent on the magnetic DIP or inclination angle, these maps may be useful in the study of radio propagation. They are included here for convenience. Magnetic DIP angles do not change substantially over time, and are not dependent on sunspot number or geomagnetic activity even though you may be required to input these values (they are common inputs for all maps).

4.8 Global Maps of Magnetic Field Total Intensity

PROPLAB uses models of the Earth's magnetic field. One of the modelled parameters required for determining ionospheric characteristics and propagation conditions, is the total intensity of the magnetic field. You can map this parameter using this option. As with the magnetic DIP angles, this parameter does not change significantly according to sunspot number, time, or geophysical activity and is included here for reference purposes. Labelled contours are in units of gammas (or nanoteslas).

4.9 Global Maps of Magnetic Latitude

It is often useful to know what magnetic latitude certain features of the Earth are located at. Since radio propagation is closely linked with magnetic latitude, it may be useful to know where a signal travels in relation to magnetic latitude. This option gives you the ability to map magnetic latitude.

4.10 Producing Maps of Modified DIP Angles

PROPLAB uses, in addition to the regular DIP angle calculations, a modified DIP angle equation that is more accurate in determining certain ionospheric characteristics. This option lets you map the modified DIP angles.

4.11 Transverse Plasma Frequency Maps

An exceptionally powerful and useful map available with PROPLAB is the transverse plasma frequency map. Imagine slicing the ionosphere vertically with a knife and looking at that sliced portion edge-on. This is what the transverse plasma frequency map provides. It is analogous to cutting a tree down and examining the internal rings. What you see in a transverse plasma frequency map is a cross-section of the ionosphere - the actual internal structure as it varies with height.

Why is a transverse plasma frequency map so valuable? Because it shows you where ionospheric tilts exist that can cause non-great-circle propagation. It shows you the various layers of ionization in the ionosphere and gives you information on their locations, intensities, etc. For

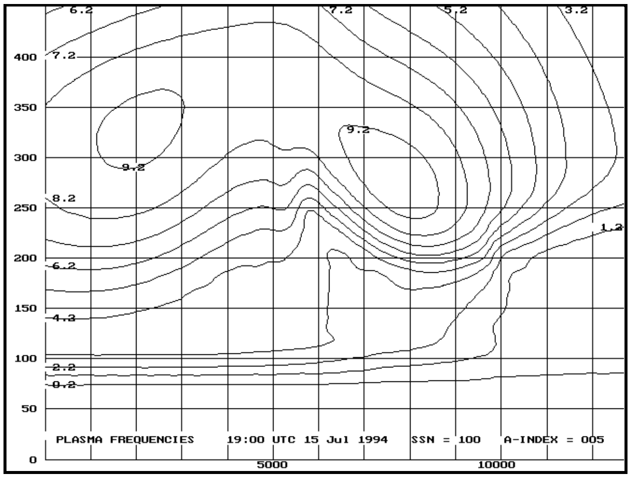


Figure 4.3: *Transverse Plasma Frequency Map*

example, Figure 4.3 is a hypothetical cross-section of the ionosphere for the path between northern Mexico and eastern Australia at 19:00 UTC on 15 July 1994 using a sunspot number of 100 and an A-index of 5. The transmitter is at the far left of the figure and the receiver is at the far right. Distances are given at the base of the figure in units of kilometers. Height is also given in units of kilometers with height intervals every 50 kilometers labelled. This figure therefore shows a cross section of the path between Mexico and Australia (a ground-distance of over 12,000 kilometers) to an altitude of 450 kilometers. The contour lines are plasma frequencies of the ionosphere. Plasma frequencies are essentially critical frequencies for specific heights in the ionosphere. For example, at the base of the ionosphere, the plasma frequency given in Figure 4.3 is 0.2 MHz. This means that a vertically-propagated signal below 0.2 MHz would be reflected from this base-layer, while frequencies above 0.2 MHz would penetrate the ionosphere at that level and travel upward until the plasma frequency increased above the operational frequency. The plasma frequency then, is the frequency of a signal required to penetrate a specific density of electrons. The plasma frequency is related to the electron density through the following equation:

$$\text{Density} = (1.24 \times 10^{10}) * \text{Plasma Freq}$$

The plasma frequency is given in MHz, and the electron density is in electrons per cubic meter. For example, a plasma frequency of 8 MHz is associated with an electron density of 9.92 x 10^{10} electrons meter^{-3}. That is, a frequency of 8 MHz would be reflected from an ionospheric layer when the electron density of that layer increased to 9.92 x 10^{10} electrons per cubic meter.

Referring to Figure 4.3 above, Australia is on the verge of sunrise, while Mexico is experiencing conditions at approximately noon. Concentrate on the far right side of the map nearest Australia. As you travel from right (Australia) to left (toward Mexico), the electron density of the D and E regions begins increasing. The contours illustrate this. There is also an attendant rapid increase in the electron density associated with sunrise in the F region of the ionosphere (above 150 km). This region of the ionosphere is tilted. A non-tilted ionosphere would be one where the contours are horizontal and flat. In this case, there is considerable tilt as you travel from Australia toward Mexico (or visa-versa), particularly in the distance range between 5,000 and 10,000 kilometers from Mexico. These are areas where non-great-circle paths may be observed.

Figure 4.3 also shows what happens as signals pass through the equatorial region. As was mentioned earlier, the height of maximum electron density in the ionosphere increases as the magnetic equator is approached. This is clearly visible in the transverse plasma frequency map as an increase in the height of the iso-ionic contours from Mexico (at zero km's) to about 5,000 kilometers where the ionospheric layers have increased in height by about 50 to 100 kilometers. For signals striking these ionospheric layers at the appropriate angles, chordal-hop type propagation may be possible due to the tilting of the ionosphere on both sides of the equator. In this case, the magnetic equator is located at approximately the 5,000 km mark.

PROPLAB will produce transverse plasma frequency maps or cross-sections of the ionosphere for any signal path. You simply specify the geographical locations of the transmitter and receiver and tell PROPLAB how high (up to 1,000 km) in the ionosphere to map, and PROPLAB will do the rest.

For greater accuracy on very-long paths such as the one from Mexico to Australia, divide the path into segments and generate transverse maps for each of those segments. The spatial resolution of the maps is dependent on the distance between the transmitter and receiver. For example, the ionospheric electron density profile for a 12,000 kilometer path is determined approximately every 500 kilometers, whereas the ionospheric electron density profile for a 4,000 kilometer path is computed approximately once every 170 kilometers, giving a higher level of spatial resolution in the map. You can approximate the interval used to determine profiles by dividing the path distance by about 24. For example, a 12,000 km path divided by 24 gives a spatial interval of about 500 km.

A word of caution is required when generating transverse plasma frequency maps with levels of geomagnetic activity above the quiet level (about 5). The contouring methods employed by PROPLAB may cause incorrect interpolations in the electron density, not because the contouring methods are inaccurate or incorrect, but because the spatial intervals that must be used to produce the maps may be too large and may leave ambiguities in the gaps that are difficult for the contouring algorithms to accurately interpolate over. These regions of possible erroneous contours typically occur with higher levels of geomagnetic activity, particularly those associated with major to severe storming (A-indices above 50 to 100). They appear on the iso-ionic contour maps as false-"bubbles" in the electron density that occur at regularly spaced intervals. These inaccuracies with higher levels of geomagnetic activity will be corrected in future revisions to PROPLAB. The iso-ionic contours associated with quiet-time conditions are more accurate and reliable.

SECTION 5 - SIMPLE RAY TRACING SCREEN

The heart of PROPLAB is the engine which traces rays through the ionosphere. PROPLAB PRO Version 2.0 has *two* hearts. This section deals only with the *simple* ray-tracing engine. It is an entire subprogram in itself and is the file named "MODEL.EXE". This program requires PROPLAB to tell it what to do and how to do it. MODEL.EXE then performs the requested ray-tracing functions and returns the results back to PROPLAB's main module.

The ray tracing screen has a large amount of information that can be (optionally) updated at regular intervals while a ray is being traced. This brief section describes the information that is available on the ray-tracing screen.

5.1 Location, Azimuth, Distance of the Transmitter/Receiver

The first six lines of the left-side panel of the ray-tracing screen define the geographical positions of the transmitter and receiver. It also lists the distance from the transmitter to the receiver in kilometers, and the azimuthal angle which should be used to transmit from the transmitter to the receiver. This angle is reckoned east of due north. For example, an angle of 90 degrees azimuth represents a position pointing directly to the east. An angle of 180 degrees points directly south, etc.

5.2 UTC Time and Operational Frequency

The time and frequency of the ray being traced can be found in the seventh and eight lines of the top-left panel of the ray-tracing screen. The time given here is always Universal Time. The frequency is always in units of MHz. Although only the first four decimal places of the frequency are printed, input frequencies can be much more accurate, extending down to seven or eight decimal places for increased accuracy.

5.3 CUR Lat and CUR Lon Statistics

These are valuable statistics that can help you diagnose where various types of signal anomalies or features occur. They represent the CURrent latitude and CURrent longitude of the signal, as it is being traced through the ionosphere using the azimuth given in Section 5.1. Using this feature, you can determine the geographical coordinates where your signal penetrates into the ionosphere, or where it crosses into the auroral zone, or where the signal loses much of its quality, or the locations of ground-hops, etc.

5.4 Signal Air Distance Statistic

The distance a signal travels from a transmitter to a receiver is not the same as the straight-line ground-distance from the transmitter to the receiver. The signal must travel further than the ground-measured great-circle distance because not only is the signal travelling horizontally toward the receiver, but it is also travelling upwards and downwards into and out of the ionosphere. The "AIR DIST" or air-distance statistic shows you how far your signal has actually travelled, not the ground-measured great-circle distance usually reported by propagation software.

5.5 CURrent Angle of the Signal

As a signal travels from the transmitter to the receiver, the angle of propagation of the signal will change from one instant to another. For example, a signal that is shot at a zero degree elevation angle, directly at the flat horizon, will increase in height by about 1 kilometer every 112 kilometers of distance it travels because of the spherical shape of the Earth. To prove this, hold a ruler flat against a sphere and see if the distance from the ruler to the center of the sphere increases with distance along the outstretched ruler. This statistic simply tells you what elevation angle the signal is headed at. It is measured from the horizontal position. That is, a zero degree angle denotes a signal travelling exactly horizontal toward the horizon. A signal that is travelling at a 90 degree angle is directed straight up toward the zenith. Positive angles are directed toward the zenith, negative angles are directed toward the center of the Earth. So, as a signal travels through the ionosphere, it will be associated with a positive angle of ascent into the ionosphere. Ionospheric refraction will gradually decrease this angle until it is travelling approximately horizontal, after which further refraction will cause the ray to bend downward. This is indicated by a negative angle value. Negative 90 degrees is therefore pointing straight down.

The small box to the left of the geographical coordinates of the transmitter and receiver (in the top-left panel of the ray screen) is a graphical representation of the current angle of the travelling ray. It shows the direction the ray is travelling both numerically, graphically, and textually. The numeric value corresponds with the "CUR Angle" statistic. The graphical method shows the actual angle of the ray by projecting a straight line at the given angle. And the textual method is similar to the graphical method except a "/" is used if the signal is travelling upward and a "\" is used if the signal is travelling downward. If the signal is horizontal, a "-" is used. This may be useful in some cases where the angle of elevation is too small to be reliably depicted in the graphical display.

5.6 The Electron Density Graph and Numeric Density

The top-central panel of the ray-tracing display shows the electron density as the signal passes through the ionosphere. This is a very valuable tool not only as a diagnostic device, but also as an analytical device. Using it, you can determine why signals may behave the way they do, or what conditions exist to refract a ray in a certain manner.

Since electron density behaves in an exponential fashion, a logarithmic display is necessary to graph changes in electron density. The electron density as a ray is being traced from one point to another in the ionosphere is graphed on-screen using the same color that is used to trace the ray itself. The base of the electron density graph begins at 1.0E+08 electrons per cubic meter and increases to about 2.0E+12 electrons per cubic meter. The second logarithmic division is therefore at 1.0E+09 electrons per cubic meter, followed by 1.0E+10 electrons per cubic meter, etc. Each subdivision is a tenth of a major division. That is, between 1.0E+10 and 1.0E+11, the subdivisions represent a change of 1.0E+10 electrons per cubic meter.

The numeric density can also be read directly off the top-right-side textual panel of the ray-tracing screen. It is the sixth line down from the top line and is labelled "Ne" (which is short for "electron density"). This value is given in scientific notation and represents the electron density per cubic meter. Since there is only room for one digit in the exponent, and since the electron density frequently exceeds values that require two digits for the exponent, PROPLAB converts the exponent into a value from 0 to 9 as usual. For exponents greater than 9, letters are used to define the exponent. The letter "A" represents 10, the letter "B" represents an exponent of 11, and the letter "C" represents the exponent 12. For example, the reported electron density of "4.6E+B" would be interpreted to read "4.6E+11" electrons per cubic meter.

5.7 Estimated Signal Strength Bar Graph

PROPLAB PRO Version 2.0 replaces the signal spreading loss bar graph with this new estimated signal *strength* bar graph. This graph now shows the estimated strength of the signal in units of decibels above one microvolt (or dBi). It is *partially* computed as the ray is being traced through the ionosphere. The final value is determined when the ray actually reaches the ground. For this reason, the signal strength bar-graph may jump around a bit as each ray is being traced from one point to another. This is normal.

It is important to remember that the signal strength computed with this simple ray-tracing technique is subject to inaccuracies that cannot be accounted for with this simpler ray-tracing method. Use the comprehensive method for more accurate signal strength computations.

5.8 Signal Quality Bar Graph

IMPORTANT: PROPLAB PRO Version 2.0 uses a new signal-quality "measuring stick". This was required because PROPLAB now computes estimated signal strengths as opposed to strict quality figures derived from appropriate estimated models. This new measuring stick attempts to relate signal strength with signal quality and also considers other degrading parameters that affect the quality of signals.

PROPLAB measures signal quality as a numerical value between 0 and 100. A value of 100 represents the best possible conditions (extremely good), while a value of zero represents complete signal loss or radio blackout conditions. PROPLAB converts the numerical value to a color-coded bar graph for easier interpretation. Areas within the blue region are associated with very good to good propagation. Areas within the green section represent signal qualities that may vary from good to fair. The yellow section of the bar graph corresponds to signals that may vary in quality from fair to poor. And signals that vary from poor to blackout conditions occur within the red area of the bar graph.

The numerical value of the computed signal quality is also converted into a textual representation of signal quality. This textual representation is displayed on the top-right panel of the ray tracing screen to the left of the acronym "Sig Qual". The available quality descriptions are as follows:

VGOOD = Very Good Quality
VG-G = Very Good to Good
GOOD = Good Signal Quality
G-F = Good to Fair Signal Quality
FAIR = Fair Quality
F-P = Fair to Poor Signal Quality
POOR = Poor Quality
P-VP = Poor to Very Poor
BLKOUT = Radio Blackout (No Signal)

Using these tools of the ray-tracing screen, it is easy to determine signal quality levels as the ray is being traced from one point to another.

If a ray is degraded to the point where the signal is blacked out, a large cross is stamped on the screen at the precise location where the ray completely deteriorates and radio blackout conditions are experienced. It is therefore easy to determine exactly where a signal dies in the ionosphere.

There may be some instances where a signal cannot be completely traced through the ionosphere. For example, PROPLAB will abort tracing a signal through the ionosphere if the signal becomes engulfed in an area where the plasma frequency exceeds the operational frequency of the signal. This can occur, for example, during transmissions that experience long-hops through the ionosphere from a region of darkness into a region of light (such as might occur during a darkness to sunrise transition). If the signal becomes trapped between the F-region and the E-region (ie. within the E-layer valley region), an indefinite number of hops will occur between these two regions until the electron density either decreases and permits the ray to penetrate either of the layers, or the electron density increases and forces the signal to become imaginary. It is this latter condition which forces PROPLAB to abort. If it occurs (which should be fairly rare), PROPLAB will impound the affect signal with a box.

Notice that the inability of PROPLAB to accurately trace rays through the ionosphere via inter-layer reflections (as described above) is related to the simpler ray-tracing technique employed. The comprehensive ray-tracing method *will* accurately compute such effects. Hence, rays are not impounded with boxes when using the comprehensive ray-tracing techniques.

5.9 Magnetic Coordinates of the Ray

The first two lines of the top-right panel of the ray-tracing screen show you the magnetic latitude and longitude of the ray as it is being traced through the ionosphere. This is a critical parameter. Many of the functions and calculations used by PROPLAB depend on reliable magnetic coordinates. For example, polar cap absorption begins to strongly affect radiowave propagation poleward of approximately 65 degrees magnetic latitude. PROPLAB uses an accurate version of the Earth's magnetic field.

5.10 Solar Elevation Angle at the Ray Location

The third line of the top-right panel tells you the solar elevation ("Sol Elv."), or the elevation angle of the Sun above the horizon, at the current geographical coordinates of the travelling ray. This is a valuable number to watch. When the Sun falls below the horizon (at sunset), this value will become negative. When the sun rises above the horizon (at sunrise), this value will become positive.

5.11 Height or Altitude of the Ray

As a ray travels through the ionosphere, the height of the ray is continually updated beside the acronym "Height" - located on the fifth line of the top-right panel of the ray-tracing screen. The given height is in kilometers.

5.12 Plasma Frequency at the Ray Height

The plasma frequency at the ray height is listed beside the "Plasma" variable in the top-right panel of the ray-tracing screen (the seventh line down). The plasma frequency is given in units of MHz.

5.13 Signal Elevation Angle

The angle of elevation used at the transmitter to broadcast the signal is given beside the variable "Sig. Elev". It is given in units of degrees above the horizon. A zero degree elevation angle therefore corresponds to a transmission directed at the flat horizon. An angle of 90 degrees denotes a vertically propagated signal.

5.14 Auroral Zone Statistics

The three lines in the top-right panel of the ray-tracing screen labelled "Aur LAT", "Aur LON", and "Aur Dist" describe the geographical position of that part of the equatorward edge of the auroral zone closest to the travelling signal. The "Aur Dist" variable tells you how far (in kilometers) the signal has spent inside of the auroral zone.

Signals that have not (or do not) pass through the auroral zone are associated with the acronym "NoZone". As is inferred, this simply means that the signal does not pass (or has not yet passed) through the auroral zones. As the signal approaches an auroral zone, the "NoZone" string will change to point to the geographical locations of the equatorward edge of the auroral zone that is closest to the signal. These variables are continually updated.

5.15 Ionospheric Distance Travelled

A radio signal typically does not suffer any significant degradation until after it penetrates into the ionosphere. The distance travelled within the ionosphere (in kilometers) is listed on the last line of the top-right panel of the ray-tracing screen (by the variable "Iono Dist"). This distance does not include the distance required for the signal to travel from the ground to the base of the ionosphere. It only includes the distance travelled by the signal WITHIN the ionosphere.

5.16 Identifying the Receiver Location

When ray-tracing signals through the ionosphere, the location of the receiver is identified by the dotted green line extending from the base of the distance grid to the top of the ionosphere. It is similarly identified in the electron density graph (the top-central panel) as a dotted green line. If the distance grid overlies the location of the receiver (effectively hiding the location of the dotted green line), the location of the receiver can be found by referencing the green arrow directly below the distance-grid base.

It is important to remember that if your distance grid is not large enough to encompass the receiver location, the dotted green line and the arrow may not be displayed on your screen. To resolve this situation, increase the distance of the grid using the Options Menu of PROPLAB described earlier.

5.17 Pausing and Skipping Traced Rays

You can force PROPLAB to pause anytime during the ray-tracing phase by pressing the "P" (or Pause) key. To resume the ray tracing procedure, press any other key. You can force PROPLAB to skip tracing rays by pressing the "S" key while individual rays are being traced.

5.18 Aborting Ray Tracing and Saving Screen Images

To abort ray tracing, press the ESCape key anytime during the ray tracing process. Once the ray tracing has been stopped (either by forcing it to abort or waiting for it to complete), you can save copies of the screen image to a GIF image file by pressing the "G" key. You can save a copy of the screen image to a PostScript compatible file for sending to a laser-printer by pressing the "P" key.

5.19 Identifying Regions of Sporadic-E

Before tracing rays through the ionosphere, PROPLAB pre-examines the path signals travel to determine if any regions of sporadic-E are crossed. If regions of sporadic-E are crossed, their exact locations are identified on the ray-tracing screen as red-colored rectangular cross-hatched regions between approximately 103 and 110 kilometers in height. Rays that intersect any portion of these sporadic-E regions may be affected by the enhanced ionization in these regions.

SECTION 6 - SIMPLE AREA COVERAGE MAPS

(Based on the Simple Ray-Tracing Technique)

One of the most impressive features of PROPLAB lies in its ability to produce broadcast coverage maps (also known as "area coverage maps"). Broadcast coverage maps are maps showing the coverage, quality, or characteristics of signals that are broadcast by radio stations (whether amateur or professional). PROPLAB combines the results of the simple ray-tracing technique results to produce broadcast coverage maps. This section shows you how this is done, and how to interpret the results.

6.1 How are Broadcast Coverage Maps Constructed?

A radio transmitter cannot broadcast without some form of radiator. The radiator is the antenna and the signal which enters the antenna is radiated outward in a direction that is dependent upon the type of antenna that is used. Antennas can be constructed to be exceptionally directional in nature where narrow beams of radio signal energy are broadcast. Others are constructed to broadcast radio energy equally in all directions. These are called omni-directional antennas. Before a broadcast coverage map can be generated, it is essential to know the approximate radiation pattern of the antenna being used to transmit or receive the signals.

PROPLAB PRO Version 2.0 uses the currently selected antenna radiation pattern during the ray-tracing phase. The broadcast coverage maps therefore take this into consideration.

Most antennas that are directional or semi-directional are designed to beam most of the radio energy in specific directions. As well, all antennas broadcast radio energy at optimum angles of elevation. That is, most of the radio energy is beamed in preferred directions and angles of elevation. To create accurate broadcast maps, it is necessary to know:

1. The direction (or azimuth) of the transmission.
2. The azimuthal spread of the transmitted signal.
3. The useful elevation angle spread of the signal.

For example, let's assume that a directional antenna beams most of its energy in a 45 degree wide azimuthal "swath". In that swath, most of the transmitted signal is directed upward at an elevation angle between 4 and 30 degrees. These are the only quantities required for PROPLAB to produce a broadcast coverage map.

PROPLAB produces a coverage map by ray tracing signals through the ionosphere using small increments of the azimuthal spread and the elevation spread of the signal. In this way, it is able to determine the broadcast coverage and quality of signals throughout the range of the transmitted signal.

For omni-directional antennas, you would use an azimuthal spread of 360 degrees, from 0 to 360, and an elevation spread of 90 degrees representing a transmitted signal being broadcast in equal intensity in all directions.

6.2 Beginning Inputs

The first prompt presented by PROPLAB is a question asking for which type of Broadcast Coverage Map to generate. To construct broadcast coverage maps from data collected using the simple ray-tracing technique, select "S" at this prompt. To use the comprehensive broadcast coverage mapping system (which uses the comprehensive ray-tracing technique), select "C".

Before any other inputs are requested, PROPLAB asks you if you want to use a previously generated dataset. If you have previously computed a broadcast coverage map and simply want to view the results of the ray-tracings, you would select "Y"es at this prompt. If you respond "N"o, PROPLAB will delete any old pre-computed datasets and begin compiling a new one.

All broadcast coverage results are stored in the file "PATHS.OUT". If you want to save a broadcast coverage map dataset, rename this file to something else so that it is not truncated and overwritten.

The first input required is the beginning azimuth of the transmission.

The second input required is the ending azimuth of the transmission. These two inputs define the limits of the antenna radiation pattern. For antennas which are semi-directional (ex. those which transmit most of their power in one direction and smaller amounts of power in the other directions), choose those directions where most of the energy is directed. The current version of PROPLAB does not provide you with the ability to define radiation patterns and produce broadcast coverage maps based on those patterns. However, future versions will build on this idea.

The third input defines the azimuthal step rate PROPLAB should use between the beginning azimuth and the ending azimuth. Smaller step rates will result in greater spatial resolution and better accuracy. However, smaller steps will also require more computation time. Larger step rates provide quicker computation but less accuracy and the resulting maps will appear more "coarse".

The fourth input informs PROPLAB to ray-trace signals no further than the maximum distance specified. If the distance between a transmitter and a receiver is 6,000 kilometers, it would be wise to specify a value approximately 2,000 kilometers beyond this point so that the coverage does not end at the receiver location, but is extended beyond by 2,000 kilometers to better define the characteristics of the transmission at those distances.

The next three inputs define the characteristics of the transmission in terms of elevation angle. For example, if a directional antenna transmits most of its power from 4 to 30 degrees in elevation, then a beginning angle of elevation of 4 degrees would be specified along with an ending angle of 30 degrees. The third of these three inputs requires you to specify the elevation angle stepping rate. Smaller step rates will result in finer spatial resolution (but again, longer computation times). The elevation angle step rate is perhaps of greater importance than the azimuthal stepping rate. An elevation angle step rate of 1 degree provides good resolution. Smaller stepping rates can be used. There is no lower limit to the stepping rate, although a stepping rate of zero obviously will not work.

Keep in mind that if PROPLAB is set up to ray trace with only one ground-hop, then only one ground-hop will be used when tracing rays through the ionosphere while generating broadcast coverage maps. Before generating these maps, it is usually wise to set up PROPLAB so that it will hop as many times as necessary to reach the destination distance. This can be done within the Options Menu discussed earlier.

6.3 Computing the Required Data

After all of the required inputs have been given, PROPLAB begins the process of computing the data required to build the broadcast coverage map. The time required to compute all of the data will depend on the values you used and the stepping rates employed. The time may vary from only a few minutes to many hours, depending on the quality of the map you are seeking.

PROPLAB begins the process of computing the data by ray tracing (with the simple ray-tracing technique) signals through the ionosphere using the starting azimuth and the starting angle of elevation. After the first ray has been traced through the ionosphere to the destination (at the maximum distance specified), PROPLAB increments the elevation angle by the elevation angle stepping rate and traces a second ray through the ionosphere using the starting azimuth and the new angle of elevation. This process is repeated until the last ray is traced representing the ending angle of elevation for the starting azimuth. When this ray has been completely traced, PROPLAB resets the angle of elevation back to the starting angle of elevation, and increments the azimuth by the azimuthal step rate previously defined. PROPLAB then retraces all of the rays from the starting angle of elevation to the ending angle of elevation at the new incremented azimuth and continues to reset the elevation angle and increment the azimuthal angle until the ending azimuthal angle is reached. The process of computing the required data is then complete when the last ray of the ending azimuthal angle and the ending elevation angle is traced. Following this, PROPLAB automatically transfers control over to the broadcast coverage map generator subprogram known as "ANALYZE.EXE".

This entire process is time-consuming, but is accurate - and can be made as accurate as time permits using smaller angles of increments. The resulting data file (in "PATHS.OUT") may be a respectably large file of many hundreds of thousands of bytes. There is no limit on the size of the data file generated. PROPLAB will handle files from several K bytes to many megabytes. PROPLAB is only limited by the size of your hard-drive.

You can force PROPLAB to abort the computation of the data by pressing the ESCape key anytime during the ray-tracing phase. This will force PROPLAB to load the ANALYZE.EXE module. Premature abortion of this phase may result in inaccurate or incomplete (or even perhaps non-existent or non-computable) maps due to insufficient data.

6.4 Types of Broadcast Coverage Maps Available

There are four types of broadcast coverage maps that PROPLAB will produce, after the appropriate data has been computed and collected (see Section 6.3). PROPLAB will produce maps of signal quality showing you the quality of signals throughout the broadcast range specified. PROPLAB will also produce maps showing you the density of rays per unit area. This latter function is valuable for determining the effects of ionospheric focusing or defocusing and therefore possible signal strength patterns. PROPLAB will also compute the time-delay of the signal from the time it leaves the transmitter to the time it reaches the ground throughout the broadcast coverage range and will produce maps showing the average time-delay per unit area. Finally, PROPLAB will compute the multipath range of signals, or ranges of time required for signals to reach specific regions. It will produce maps of multipath time-spreads, which is exceptionally useful information for packet-radio systems or other digital-type communications.

Figure 6.1 is a sample broadcast coverage map showing signal quality from an omni-directional antenna located in Colorado broadcasting over many thousands of kilometers. The image is of relatively poor quality due to the dithering that was required. Actual final maps are

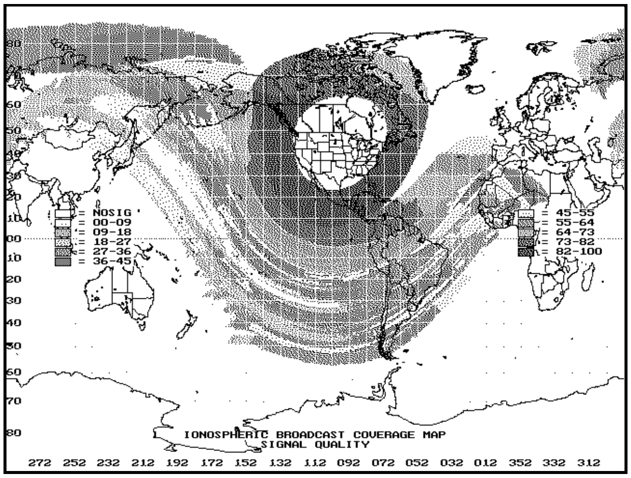


Figure 6.1: *Dithered High-Quality Broadcast Coverage Signal Quality Map*

filled with color, not dithered. The key in the center left and right sides of the figure define what each of the colors mean. Unfortunately, this is difficult to adequately discern in Figure 6.1, but shows you enough information for our needs. Each individual color is associated with a range of signal quality numerical values ranging from 0 (blackout, or no signal [NOSIG]) to 100, or extremely good signal quality. Using this key, you can determine the quality of signals anywhere on the map.

Some very useful information can be derived from this map. For example, areas where no signal is present are shown as areas having no filled colors. The skip distance for this example is easily defined as the inner circle-type boundary between no signal and a strong signal. Notice how the skip zone is elongated to the north and east away from the transmitter in Colorado. This is due to the failure of the ionosphere to reflect signals from the lower ionospheric layers (E region, for example), perhaps brought about by the setting Sun. Signal quality becomes very good just outside of the skip zone where MUF focusing is occurring. Best signal coverage occurs generally to the south and covers most of South America to some degree. Signals should also reach Hawaii, but with only fair signal quality. Paths more directly toward the east and west (and northeast/northwest) become poor rapidly. On the frequency used to produce this map, signals penetrate the ionosphere or are lost through other processes fairly rapidly with distance.

Best signal coverage (although not necessarily the best signal quality coverage) occurs toward the south. As well, most of the continental U.S. is unable to receive the transmission due to the size of the skip zone indicated. However, Florida and a portion of the extreme southeastern and eastern coastal states would receive an exceptionally good signal since these regions are just outside of the skip zone and are in the regions of high signal quality, as are portions of the extreme northwestern states, northern British Columbia, and northwestern Canada. Extreme southeastern and eastern regions of the U.S. that are almost directly on the skip-zone boundary would also likely experience potentially severe fading caused by the close proximity of the skip-zone. This is known as MUF or skip fading and can result in very deep fade-outs followed by very strong fade-ins. Highest signal qualities for this scenario would occur over central America and southern Mexico - within the first-hop signal distance and outside of the skip zone. The signal deteriorates from there due to multi-hop propagation and associated absorption, etc.

Although not shown here, a similar broadcast map showing the density of rays converging within certain regions would be useful for determining areas where ionospheric focusing or defocusing may be occurring. Together with the signal quality map, it is possible to determine where signal qualities correspond with ionospheric focusing to produce exceptionally good propagation conditions. Although ionospheric focusing may, in theory, increase signal strength, you must keep in mind that signals may differ in total distance travelled to produce multi-path types of distortion and decreased signal quality. For example, a two-hop signal may focus with a one-hop signal to perhaps increase signal strength or produce destructive interference or even beating between the two signals. In either of the two latter cases, signal distortion and fading would be observed that might decrease signal quality even if the signal strength is increased.

For maps depicting the density of rays (focusing or defocusing), the values within the key indicate how many rays strike the ground within a specified binning distance (described shortly).

Transmissions that are digital in nature may find the multipath ranging maps exceptionally useful. Digital transmissions are not as dependent upon the quality of a signal path as they are upon the multipathing that is occurring over the path. Digital information cannot be transmitted at high speeds if multipathing is occurring, because multipathing causes the pulses (or packets) of transmitted information to become entangled with each other and/or distorted into garbage.

Multipathing is what happens when one or more signals travel different paths to the same destination. Each signal takes a specific amount of time to reach the destination. For signals that travel farther to reach a given destination, the signal will arrive at the destination sooner than a signal that travels a shorter distance to the destination. The time difference between arriving signals is what causes multipathing and is also what is responsible for limiting the speed and/or quality of digital transmissions. For digital communications, paths with the lowest possible multipath ranges (or time-spreads of arriving signals) are desired. These areas typically tend to occur near the maximum usable frequency, provided all of the signals are being reflected from a single ionospheric layer (this usually occurs near the MUF anyway).

PROPLAB will produce broadcast coverage maps of multipath ranging information showing you the time-spread of signals (in milliseconds) anywhere within the broadcast coverage range specified. Voice communications can usually deal with fairly strong propagation multipathing before deteriorating to non-intelligibility. However, multipathing will degrade signal quality by increasing distortion and fading. Multipath ranging maps may therefore be useful to help determine possible areas of distortion and fading.

After you have ray-traced the signals to produce the output dataset in the file "PATHS.OUT", you can construct any of the four available maps without having to retrace rays.

The last map produced by PROPLAB is a simple map showing you the average time (in milliseconds) required for signals to travel from the transmitter to any point within the broadcast coverage range area. This is known as a propagation delay map.

6.5 Required Map-Generation Inputs

PROPLAB first asks you whether you want to use a previously generated map or a fresh map from the map library. If you have previously generated a broadcast coverage map and wish to supplement it with additional information gathered by another ray-tracing run, select "S" to use the previously generated broadcast coverage map. Alternatively, if you have previously generated a map of maximum usable frequencies (etc), or a map showing the location of the auroral ovals, sunrise/sunset grayline, sporadic-E, etc, you may use that map instead of a fresh map from the map library by selecting to use a previously "S"aved map. You therefore do not need to use only a previously saved broadcast coverage map, but can use any map that was previously saved by pressing the "S" key while the map was displayed on-screen.

If you choose to select a fresh map from the map library, the next menu shows you the available maps in your map library and asks you to select one of those maps.

The next series of inputs defines the geographical location of the transmitter responsible for the data in the file "PATHS.OUT". Type the geographical coordinates at the appropriate prompts.

PROPLAB produces the broadcast coverage maps by binning the data into groups of similar distances. For example, to determine the effects of ionospheric focusing and defocusing, PROPLAB counts the number of individual rays that strike the ground within a specific area of the transmitter. The default binning distance is 500 kilometers, so PROPLAB counts the number of ground-striking rays within a 500 km zone. This zone is moved outward away from the transmitter at a specific user-selectable "Stepping distance" rate, until the zone is at the maximum distance previously defined when the broadcast map generation process was first started.

Following the input of the binning distance and the stepping distance rate, you are presented with a menu and are asked to select the type of broadcast coverage map to generate (signal quality, multipath ranging, etc). Choose whichever map you need to generate and press ENTER to begin the process.

The time required to BEGIN drawing the map depends on the size of the dataset file "PATHS.OUT", PROPLAB must first scan through the data and precompute various quantities before the map drawing phase can begin. While PROPLAB is busy doing this, a box with "Processing Data" will appear on your screen. Be patient. After PROPLAB has pre-scanned the data, the map will be drawn on-screen, after which the geographical map showing the continents and islands will be superimposed. After the map has been drawn, you are given access to the commands given in the following section.

6.6 Available Commands while Viewing Maps

PROPLAB will convert any of the graphical maps displayed into equivalent graphic image files (or GIF images) by pressing the "G" key while the map is displayed. The screen can be converted into a PostScript-compatible file that can later be sent to a laser-printer by pressing the

"P" key. Screen images can also be saved to disk in a special format by pressing the "S" key. This latter command permits you to integrate broadcast coverage maps in with other types of maps. For example, after generating a broadcast coverage map, you can use the contouring capabilities of PROPLAB to superimpose contours of maximum usable frequencies or critical frequencies, etc, on the broadcast coverage map. Resulting maps may be invaluable and provide, for example, the broadcast coverage signal quality along with contours of maximum usable frequencies, solar zenith angles, and any other information that may be helpful to interpret the quality of signals within the broadcast coverage of the transmission.

PROPLAB does not normally provide a key defining what each of the colors mean in the broadcast coverage map. To display the key, press the "L" key on your keyboard. The meaning of each of the colors will then be displayed on-screen.

If you are not interested in saving the screen image, press any other key and PROPLAB will either return you to the DOS prompt (if you began running ANALYZE from the DOS prompt), or will return you back to PROPLAB's Main Menu.

SECTION 7 - COMBINING MAPS

Once you have become more familiar with the general functions and operation of PROPLAB, you may begin tapping into a few of the more powerful features of PROPLAB, such as combining maps.

PROPLAB is capable of presenting its results using a variety of different map projections. The ability to combine maps magnifies the usefulness of the software by many magnitudes by making it possible to present a great deal of information on-screen at once.

For example, during a geomagnetic storm, the location of the auroral zones expand equatorward, affecting signal paths in the middle latitude regions. As well, signal qualities decrease and multipathing may increase. Signals may also be affected by sporadic-E. Maximum usable frequencies will decrease. PROPLAB provides you with all of the tools required to fully analyze all of these quantities. It will produce maps showing you the location of the auroral ovals, the location of sporadic-E, the path travelled between the transmitter and receiver, as well as maps showing maximum usable frequencies and signal qualities. However, all of this information is not available on a single map. You would normally have to generate each map for each quantity separately and then reference each separate map individually. PROPLAB gives you the power to combine maps or superimpose data onto previously constructed maps.

Each time a graphical image is displayed (with the exception of the ray-tracing screen), you have the option of pressing the "S" key to Save the graphical screen image in a special format to disk. This is the key to combining maps. Every time an application runs that may result in a generated map, the question is first posed: do you want to use a previously generated map or a map from the map library? To use a map that has been previously saved in the special format, choose the option to use a previously generated map. That application will then use the map saved to disk in the special format instead of pulling out a fresh map from the map library. This is the process used to combine maps.

Let's say you want to generate a broadcast coverage map showing you the quality of signals within the broadcast area as well as global maximum usable frequencies for a 4,000 kilometer path. Your first step would be to generate the broadcast coverage map using the material presented in Section 6. This would involve a fair amount of ray-tracing activity. After that process completed, you would create the actual broadcast coverage map. When this map is finished being drawn, press the "S" key to save that screen image to the special disk format, then return to PROPLAB's Main Menu. Next, select the option to generate global ionospheric maps. After this subprogram has been loaded, you will again be presented with the question of whether or not to use a previously generated map. Inform the application to use the previously generated broadcast coverage map that was saved by pressing the "S" key. PROPLAB will then automatically place that saved screen image on-screen and will superimpose all maximum usable frequency contours for 4,000 kilometer distances on that broadcast coverage map. The resulting product is a map combining the broadcast coverage map with the maximum usable frequency contour map.

While this combined map is on-screen, you can press the "S" key again to save that map to disk in the special format and use that map for superimposing other material upon. For example, you could superimpose contours of solar zenith angles on the combination broadcast coverage and MUF map previously generated. This time, you may want to choose a different color for the solar-zenith angle contours so that the solar zenith angle contours can be differentiated from the MUF contours. Many maps of different types can therefore be superimposed on one another to provide a wealth of information on one screen.

SECTION 8 - ALL-BAND SPECTRUM ANALYSIS

(Using the Simple Ray-Tracing Technique)

PROPLAB comes with a powerful new function to produce oblique sounding ionograms, giving you the ability to analyze propagation characteristics and conditions throughout a wide range of frequencies. This function is imbedded within the Simple Ray Tracing submenu and can be found by selecting Main Menu option 1,"S", submenu option 4. The following discussion pertains strictly to this function.

8.1 What is an Oblique Sounding Ionogram?

Ionograms are produced using an instrument known as an ionosonde. Ionosondes are simply special radio transceivers (radio transmitter/receiver combination) designed to transmit signals into the ionosphere and measure the character of the energy that is returned from the ionosphere. In this respect, they are similar to radar guns.

We established earlier that signals which are propagated into the ionosphere are reflected according to the density of electrons present in the ionosphere. Regions of high ionospheric electron density are capable of returning higher frequencies. This behaviour is the foundation upon which we are able to probe the ionosphere.

Ionosondes probe into the ionosphere by using a sweep-frequency transmitter. That is, the frequency of the transmission is swept (or increased) from low frequencies to high frequencies. As the signals from the low frequencies penetrate the ionosphere, they are reflected back to the transmitter and the receiver picks up these reflected transmissions. Since low frequencies can be reflected by relatively low electron densities, these low-frequency reflections give us an idea of the content of the lower portion of the ionosphere. As the frequency of the transmitter increases, the signals penetrate deeper into the ionosphere before they are returned to the Earth. Eventually, as the frequency continues to increase, the frequency will exceed the critical frequency of the F2 layer and never return to the Earth. By carefully tracking all received signals with the receiver as the transmitter frequency is increased, we can build a "picture" of the ionosphere up to the maximum density of the F2 layer. These "pictures" are known as ionograms, and can give you a wealth of information regarding the state of the ionosphere.

Oblique ionograms are simply pictures of the ionosphere produced by measuring all of the received energy propagated from a transmitter some distance away, as the frequency of the transmitter is swept from low to high frequencies. Using oblique ionograms, you can easily determine optimum working frequencies, maximum usable frequencies, minimum usable frequencies, the extent of signal multipathing present on specific frequencies, and much more. We will discuss the proper interpretation of these features shortly.

PROPLAB produces oblique sounding ionograms between two points by sweeping the HF spectrum at the transmitter and measuring the signals that reach the desired receiver. The process is rather complex and can be time-consuming for detailed results, but the information which can be gathered from such an analysis is well worth the time.

8.2 Phase 1: Collecting the Required Data

There are two phases to producing Oblique Ionograms with PROPLAB. The first phase is to collect the data. The second step is the analysis phase, which is discussed in Section 8.3. This first data-collection phase requires the most time, but is extremely simple to set up.

First, you must make certain that the transmitter and receiver locations and parameters are properly established (using option 8 of the Main Menu). Be sure that the relative transmitter power is set properly, as well as the geomagnetic A-index and the sunspot number or solar flux. Also be certain that the date and time (local or UTC) is also properly entered. These are the most critical parameters.

If sporadic-E may affect the signal path, make sure you use option 3 of the Main Menu to set-up the regions of sporadic-E. If solar flares or PCA might inhibit communications, enter the appropriate data in option 8 of the Main Menu.

Make sure that all of the items in option 8 of the Main Menu are properly established for the signal path you wish to analyze, then select option 1 of the Main Menu to enter the Ray-Tracing menu. Follow this by selecting suboption 4 (Generate Oblique Sounding Ionogram) of the Ray-Tracing menu.

You will be asked whether you want to analyze previously generated ionogram data. If you have previously collected data, you can skip the data-collection phase and go straight to the analysis phase by typing "Y" (Yes) at this prompt. If you do not want to analyze a previously collected dataset, type "N" (No).

You will now be asked whether you want to append collected data to the existing ionogram database. If you previously collected data, but want to extend the data to improve the accuracy of the results, you will want to select "Y" to append all collected data to the existing database. If this is your first data-collection run (or if you are beginning to collect data on a different signal path), then select "N" so that any existing data is truncated.

A paragraph of information is next displayed which should be entirely read. It simply explains what is about to happen and how to respond to the following prompts.

The series of prompts that follow specify details of the transmission, the frequencies to use, and step rates. The first three prompts define the antenna radiation pattern of the transmitter (beginning angle of elevation, ending angle of elevation, and the step rate to use when ray-tracing). An omni-directional antenna transmits power into space approximately equally in all directions. We only consider the vertical elevation above the horizon since the antenna is assumed to already be pointing at an optimal azimuthal location toward the receiver. An omni-directional transmitter would have a starting elevation angle of 0.0 degrees, and an ending angle of elevation of say 89 degrees. *Avoid using ending elevation angles of 90 degrees, as the near-vertical propagation of low-frequency signals may result in lengthy computation times during this phase.* Values close to 90 degrees can be used instead, such as 89.0 or 89.5. After inputting the starting and ending elevation angles of the transmission, you are prompted for the elevation angle step rate. Since PROPLAB traces rays through the ionosphere from the starting elevation angle to the ending elevation angle, a step rate must be specified so that PROPLAB knows how to progress from the starting to ending angles. The lower the step rate, the greater the resulting accuracy will be, but the longer the computation time will also be. A step rate of 0.5 degrees to 1.0 degree yields reasonable accuracy.

The prompt asking to "Update the Screen Statistics at what rate" does not affect the accuracy of the results, but will affect the speed that PROPLAB produces results. This prompt determines how frequently PROPLAB should update the ray-tracing screen statistics. Large values (in excess of say 200 to 300) will speed up the ray-tracing slightly by updating the statistics section of the screen less frequently. If you like to keep close tabs on the statistics, then use a lower value.

The final three prompts deal with how the transmitter frequency is to be varied. You are asked to type in the starting frequency, the ending frequency, and the frequency step rate to use during the ray-tracing phase. To analyze propagation conditions between the transmitter and receiver between 1.0 MHz and 40 MHz, use a starting frequency of 1.0 MHz and an ending frequency of 40.0 MHz. The step rate you use here will determine the resolution of the results. For high-resolution, use low step increments of say 0.25 MHz or less. For faster computation and low-resolution results, use step rates of 0.5 to 1.0 MHz. Keep in mind that as the step rate is increased, the resolution of the results will decrease, making it harder to see perhaps smaller features in the ionogram and perhaps decreasing the accuracy of the results in the process.

After you have responded to these prompts, PROPLAB begins collecting the necessary data by rigorously ray-tracing through the ionosphere from the transmitter to the receiver, sweeping both the transmitter frequency and the elevation angle of the transmission.

You can halt the data-collection phase at any time by pressing the ESCape key. Write down the current frequency and elevation angle being ray-traced before aborting so you can continue the processing from that point later, if you desire, by appending the future collected data to the database of results.

8.3 Phase 2: Analyzing the Results

After PROPLAB has finished the data-collection phase, the utility program "SOUNDER.EXE" is loaded and executed. This utility reads the results from the database file "CHIRP.OUT", processes the data, and displays the results on-screen. This utility can be optionally run from the DOS command-line after the database has been built.

Provided the database file "CHIRP.OUT" exists and contains data, PROPLAB will display the geographical location of the receiver as well as the great-circle distance to the receiver, and ask you if you want to change the location of the receiver. Since PROPLAB ray-traces through the ionosphere, a profile of propagation conditions can actually be computed anywhere between the transmitter and receiver, provided the chosen location lies along the same great-circle path. If you choose to change the location of the receiver, you will be asked to type in a new great-circle distance to the receiver. This distance is then later converted into appropriate geographical coordinates and are displayed along with the final results. You cannot specify a new receiver location beyond the distance of the receiver used during the ray-tracing phase. It must lie between the transmitter and the receiver.

If you do not wish to alter the location of the receiver, press ENTER or type "N " and press ENTER. This will give you the second prompt which asks you to accept signals that reach the ground within +/- how many kilometers of the receiver. In other words, it asks you to specify how closely signals must approach the receiver location before they are accepted as having actually reached the receiver. This is an important prompt and deserves further explanation.

In reality, radio transmissions are composed of an infinite number of "rays" that travel individually through the ionosphere. As a result, the reflected radio energy hits the ground at an infinite number of points along the great-circle path towards the receiver. You can therefore sample almost any location along the great-circle path and measure signal energy reaching the ground. The same does not apply to PROPLAB. Since PROPLAB must individually trace each ray through the ionosphere, it is not practical to permit an infinite number of rays. To speed up the procedure, it is necessary to limit the number of rays that are traced through the ionosphere. If a significant number of rays are traced, the results will be similar to what would be expected in a realistic situation where an infinite number of rays are used. If a smaller number of rays are used, there may be gaps along the great-circle path where no rays reach the ground. In order to build an oblique ionogram, the receiver must receive energy from the transmitter. But if a smaller number of rays are used, it is possible that none of the propagated rays will *EXACTLY* reach the receiver. Several rays may straddle the receiver, hitting the ground perhaps only a few tenths of a kilometer or a few kilometers from the receiver location. To solve this situation, we must assume that each transmitted ray represents many individual rays with slightly differing characteristics (slightly different elevation angle of transmission, slightly different frequency, etc). If we make this assumption (which is true enough), we can expect that for each traced ray which hits a specific location, there will be an infinite number of imaginary rays which strike the ground at slightly differing locations from the principal traced ray. All will strike the ground a few tenths of a kilometer or a few kilometers on either side of the traced ray, effectively eliminating all gaps present.

If we use this theory and reasoning, then this prompt makes sense. We are, in essence, saying that if a traced ray strikes the ground within say +/- 50 kilometers of the receiver, then an associated imaginary ray has actually arrived at the receiving antenna with characteristics close enough to the traced ray that the two rays (the imaginary ray and the traced ray) can be considered the same. As a result, all rays that reach the ground within +/- 50 kilometers of the receiver are assumed to have been received by the receiving antenna and are processed.

If you collected data using relatively large step increments, there will be relatively few traced rays, implying that each ray must be associated with an infinite number of imaginary rays that have more substantial differences or vary in characteristics more seriously than the traced ray. Each traced ray must therefore be assumed to cover a larger area of ground in order to simulate true conditions realistically. As a result, if there are a relatively small number of traced rays that are used, you may have to accept signals that strike the ground within a larger area than just 50 kilometers. You might need to accept signals within +/- 200 kilometers of the receiver. For very large numbers of rays, the concentration of rays that strike the ground along the great-circle path will be sufficient to use smaller values, say within +/- 5 or 10 kilometers of the receiver. You can experiment with the values, but keep in mind that you want to keep this window as small as possible while still retaining a respectable number of samples to build reliable results.

The next prompt asks you whether you want to analyze all rays regardless of their signal quality. In most cases, you will want to consider only those rays that are associated with a signal quality above zero - in other words, one which has not "blacked-out" due to absorption or other factors. This filters out all of the signals that would not be received because they have been degraded to the point of uselessness and displays only those signals that you should be able to "hear" at the receiver. If you're curious about the character of those signals that never reach you, you can specify "Y" at this prompt to accept all signals that reach the receiver, whether they are useless or not.

The last major prompt asks you for the type of analysis you want to carry out: an analysis of propagation delays (by pressing "P"), or an analysis of elevation angles (by pressing "E"). The propagation delay analysis shows you how long it takes the received signals to reach the receiver, after they leave the transmitting antenna. The results given by this analysis are far-reaching and exceptionally useful. The elevation-angle analysis shows you what transmission elevation angle was used for each of the signals that were received by the receiving antenna. This plot is likewise, a very useful tool and can give you a great deal of insight into optimum transmission angles. We will discuss the features of these plots shortly.

If you produce a propagation-delay plot, you will be asked if you want the computer to automatically compute the resolution of the display, or if you want to control this yourself. Press ENTER or type "Y" to have the computer do this for you automatically. To set the resolution manually, you are asked for one final piece of information: how many milliseconds should the grid display? A single-hop E-region reflected signal requires a little more than approximately 3 milliseconds to travel from the transmitter to the ionosphere and back to the ground. A two-hop E-region reflected signal will likewise require twice that time. An F-region reflected signal may take a range of differing times, depending on how deeply the signal passes into the ionosphere, the frequency used, etc. In most cases, a value of 4 milliseconds will be more than adequate and may produce a more realistic (similar to an actual ionogram) result than an auto-computed value. But if you're unsure, let the computer do the work for you.

If you produce an elevation-angle related plot, you will be asked two final questions before the data is finally processed. You will be asked to type in the minimum elevation angle used during the ray-tracing phase, and the maximum elevation angle used during the ray-tracing phase. These values determine the grid size.

After you have answered all of the prompts, PROPLAB begins processing the database of information contained in "CHIRPS.OUT". You will be told to please wait as the data is processed. After the data is processed, the results are displayed on-screen.

8.3.1 The Propagation-Delay Plot

Figure 8.1 shows a sample propagation-delay plot produced over the path from Hawaii to Colorado. The transmitter was located at Hawaii. The analysis was produced for June 30, 1994 at 15:00 UTC during geomagnetically quiet conditions. This corresponded to the declining phase of solar cycle 22 and as a result was associated with a relatively low sunspot number of about 30.

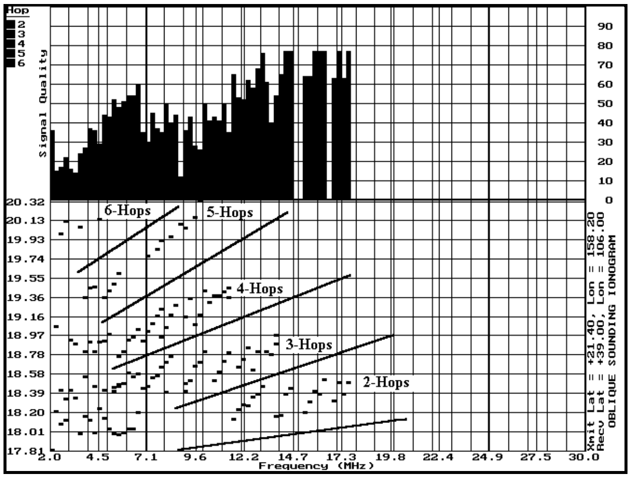


Figure 8.1: *Oblique Sounding Propagation-Delay Ionogram from Hawaii to Colorado on 30 June 1994 at 05:00 UTC during geomagnetically quiet conditions.*

The lower panel of this figure shows you how long it took signals to reach Colorado from the Hawaiian transmitter, in milliseconds. Each plotted block represents one traced ray which hit the ground within the specified acceptable distance from the receiver. Although this figure does not show it, the full-color display produced by PROPLAB plots each block using a specific color that corresponds to the number of hops that was required for the signal to reach the receiver. Since the display in Figure 8.1 is black and white, we have grouped those rays which have common numbers of hops. At the extreme upper left coroner of the figure, a Key exists which (on full-color displays) shows you what plotted colors correspond to certain numbers of hops. Notice that there were no signals that arrived at the receiver using a single hop. At least two hops were required to traverse the 5,300 kilometer path from Hawaii to Colorado.

The frequency separation grid lines shown in Figure 8.1 require further explanation. Each labelled frequency (ex. 9.6 MHz) is associated with a bright WHITE vertical line (which is not discernable in the black and white rendition of this figure). At each whole numbered frequency (8.0, 9.0, 10.0, 11.0 MHz, etc), a LIGHT GRAY vertical line is plotted. For this reason, some lines may appear irregularly spaced in the frequency grid for the figures which have been reproduced here. However, while running PROPLAB, they are easily discerned from one another.

The upper panel of Figure 8.1 describes the estimated signal quality. *Please note that the given signal quality is not to be taken as an absolute. The computed signal quality is simply the average signal quality of all rays that arrive at specific frequencies. They do not take into consideration effects of strong multipathing, ionospheric focusing, etc. For these reasons, the given signal quality should be used as an estimate only and a guide to the general quality of* *signals that can be expected.* We will improve the quality computation figures in future releases.

Figure 8.1 shows that five modes of propagation are possible between Hawaii and Colorado on the high-frequency bands: 2 hop mode, 3 hop mode, etc, to the 6 hop mode. The lower the frequency, the more modes that are supported. A greater number of modes can have advantages over single-mode communication in that should one mode fail, other modes still exist to receive the signals on. However, larger numbers of modes (or hops) increase the multipathing, or the time-spread between received signals. Multipathing creates signal distortion since there may be several signals from the transmitter arriving at the receiver at slightly different times. This can cause destructive interference, distortion, beating between the signals, and strong to severe fading. But for many types of communications, these types of signal degradation might not seriously impede the intelligibility of signals (for example, CW communications). Other types of communications (digital) can be rendered useless with multipathing.

In Figure 8.1, there is almost a 3 millisecond range in reception times for signals arriving at Colorado from Hawaii. There is also a great deal of overlapping between signals of various types of modes. For example, at 7.1 MHz, there exist three modes of propagation: 3-hop, 4-hop, and 5-hop paths. This is determined by scanning the graph vertically from the 7.1 MHz grid line and examining all those signals of differing colors that arrive at the receiver. In this example, there were three rays received at this frequency at approximately 18.4 milliseconds (ms), 19 ms, and 19.75 ms. The time spread is therefore (19.75 - 18.4) about 1.35 ms between the slowest and fastest arriving signals. This is a tolerable time-delay for voice-based communications and is not too bad for digital communications either. The maximum rate (in bits per second) of digital communications is approximately equal to the reciprocal of the range of multipath propagation times. In this example then, digital communications might be supported on 7.1 MHz at a maximum rate of approximately (1 / 0.00135) 741 bits per second, or about 74 baud. Note that this analysis is based on the data collected to form Figure 8.1. The accuracy of the assessment is therefore dependent on the amount of data collected.

From Figure 8.1, the highest signal qualities appear to be associated with the 2-hop mode of communications. This is primarily the result of reduced distortion from low multipathing and relatively low signal degradation. There are two regions where no signals were observed. This void exists at about 14.0 to 14.5 MHz and again near 16.75 MHz. Signals from Hawaii at frequencies near these voids would not be received at Colorado.

The maximum usable frequency (MUF) from Hawaii to Colorado is easily determined from Figure 8.1. The MUF is about 17.5 MHz. This is a realistic MUF value that surpasses the accuracy of the MUF-computations available at PROPLAB's Main Menu Option #2. Why are these MUFs more accurate for paths greater than 4,000 kilometers? PROPLAB computes the MUF in Main Menu Option #2 by computing the MUF at two control-points approximately 2,000 kilometers away from the transmitter and receiver. It then selects the lower of these two MUFs. PROPLAB does not rigorously ray-trace through the entire length of the path when computing long-distance MUFs. Nor does it consider effects of sporadic-E on the MUF. The oblique-ionogram technique used to produce Figure 8.1 does rigorously ray-trace throughout the entire length of the path. It makes no assumptions or estimations by limiting the analysis to two control points. And it will consider the effects of sporadic-E on the MUF. For this reason, you can determine actual MUFs between any transmitter or receiver using these plots.

It is possible to reanalyze propagation conditions at any distance between the transmitter and receiver by changing the location of the receiver when so asked. The first question posed by the PROPLAB Oblique Sounder Ionogram utility (SOUNDER.EXE) is "Change Receiver Location?". By responding to this question with "Y", you are asked to type in a new distance to the receiver.

Figure 8.2 shows the results of a reanalysis between Hawaii and a point at about 36N 126W, off the California coast. This was done by changing the distance between the transmitter and receiver from 5,300 kilometers to 3,500 kilometers. Notice that we are still analyzing conditions along the same great-circle path, but at a different distance from the transmitter.

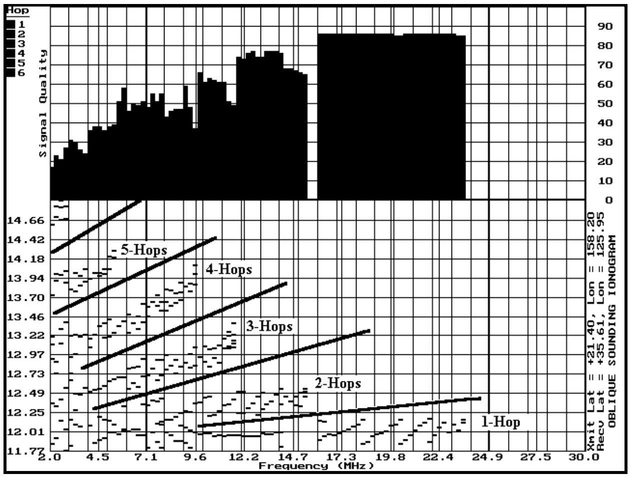


Figure 8.2: *Propagation-Delay Ionogram from Hawaii to 36N 126W made from the same data as Figure 8.1 by changing the distance from 5,300 km to 3,500 km.*

The results shown in Figure 8.2 differ substantially from those depicted in Figure 8.1. First, notice the increase in the MUF to about 23.5 MHz, made possible by the ability of the ionosphere to return single-hop signals from a portion of the ionosphere that is more intensely ionized. At 05:00 UTC on 30 June, Hawaii is almost directly on the sunset grayline. As the signal travels from Hawaii to 36N 126W (towards Colorado), the electron density in the ionosphere will decrease because the signal is moving into deeper areas of the night. The 5,300 kilometer path requires two hops. The first hop would have been associated with an MUF near 23 MHz, but the second hop would be associated with an MUF closer to 17.5 MHz. Higher-frequency signals would penetrate the ionosphere due to the decreased night-time electron density present at the second-hop location. For this reason, the MUF for the 3,500 kilometer path to 36N 126W is higher than the MUF for the path to Colorado.

Notice also that the various modes of communication are better defined in Figure 8.2. There are also a greater number of rays received throughout the frequency range plotted, which improves the visibility of certain features in the plot. The overall signal quality is also higher.

Referring to Figure 8.2, you can determine the MUF for signals of any number of specific hops. For example, it was already shown that the 1-hop MUF was about 23.5 MHz. Similarly, by examining the maximum frequency on the ionogram in Figure 8.2 for 2-hop signals, it can be seen that the 2-hop MUF is about 15.25 MHz. Similarly, 3-hop signals are associated with an MUF of about 11.5 MHz, 4-hop signals with an MUF of 9.5 MHz, 5-hop paths with an MUF of 5.25 MHz, and 6-hop paths with an MUF of about 2.75 MHz. Since signals are usually focused and become stronger near the MUF, you can expect signals with multi-hop MUFs to be stronger than might normally be expected. However, signals which have multiple ground hops also lose signal strength due to ground absorption and multiple ionospheric crossings, they might therefore be weaker than single-hop signals.

With this information in mind, consider what communications might be like along the 3,500 km path depicted in Figure 8.2 from Hawaii to a ship off the California coast near 36N 126W on 11.5 MHz. First, determine what modes of propagation are possible on this frequency by scanning vertically up from the 11.5 MHz grid region. There are three modes of communication possible on this frequency: 1-hop, 2-hop, and 3-hop modes of communication. The signal strength depicted in the upper panel of the figure suggests "fair" signal quality should exist on this frequency. Signals requiring only one hop will likely have fairly strong signals. However, a strong signal can be associated with poor quality if multipathing is a factor. And in this case, multipathing will play a part in determining signal quality. Signals that require 2-hops before reaching the receiver will have slightly less signal strength than single hop signals, and will be out of phase with the stronger single-hop signals by about 0.5 milliseconds. This is a fairly small time-spread and will not significantly degrade communications, but may contribute to a slightly "fuzzy" level of voice communications. Now consider the final mode of communications, the 3-hop mode. Notice that our 11.5 MHz frequency lies on-top of the MUF for 3-hop paths. As a result, the signal strength of the 3-hop signals may be stronger than we might otherwise anticipate. In addition, these signals will require an additional 1.5 milliseconds from the time the single-hop signals arrive, before they reach the receiver. This will introduce additional and more serious distortion into the received waveforms, degrading the received signal a bit more. In this case, the given signal quality may in actuality be close to "fair" on 11.5 MHz.

Notice how the quality suddenly improves (goes to higher numbers) as soon as the MUF for 3-hop signals is passed. At 12.0 MHz, the signal quality jumps up to "good" values, primarily because the additional distortion introduced by the 3-hop signals is no longer present. Only 2-modes of propagation are possible at 12.0 MHz: single hop and dual hop communication modes. The relatively small multipathing (0.5 ms) that exists between the 1-hop and 2-hop signals is (in this case) negligible. It is interesting to note that the decrease in propagation delay time-spread between 11.5 MHz (1.5 milliseconds) and 12.0 MHz (0.5 milliseconds) would have a significant impact on the maximum speed of digital communicators. In this instance, the reduction in multipathing would increase the maximum speed of digital communications by about a factor of 3, simply by judiciously choosing low-multipath frequencies. This illustrates a small portion of the value of performing an oblique-ionogram type of signal path study.

Figure 8.2 still shows a region where no signals were received near 15.0 to 15.5 MHz. Notice that the void in the frequency spectrum has increased in frequency from Figure 8.1 (where it resided between about 14.0 and 14.5 MHz) to Figure 8.2. The fact that this region of "blackness" in the frequency spectrum was also evident in the 5,300 kilometer plot in Figure 8.1 suggests that the anomaly is in all likelihood real and should be avoided. We could not be so certain of this if the density of traced rays (during the data-collection phase) was low. In these examples, a sufficient number of rays were traced to produce reasonably realistic and accurate results.

8.3.2 Elevation Angle Plots

Figure 8.3 is a plot of elevation angles with frequency, as opposed to propagation delay time with frequency. It was derived from exactly the same data as Figure 8.2 for the 3,500 km path from Hawaii to the ship at 36N 126W.

In a nutshell, this plot shows you what transmission angles of elevation are required for signals to reach the receiver at 36N 126W on specific frequencies throughout the HF spectrum. It is an extremely valuable tool for determining optimum transmission takeoff angles to remote locations.

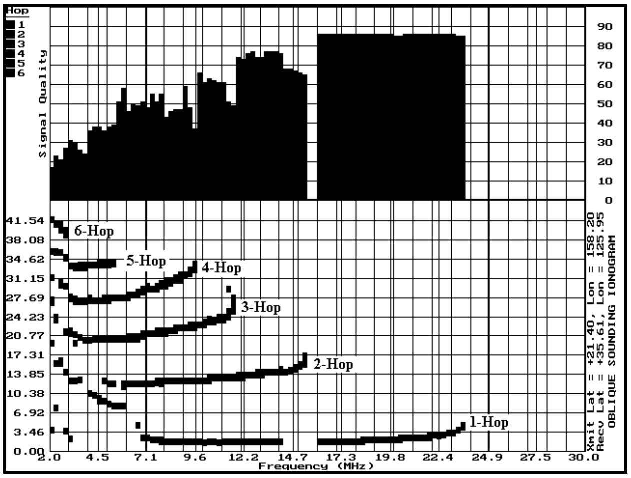


Figure 8.3: *Elevation Angle Ionogram from Hawaii to 36N 126W (3,500 km). Compare with Figure 8.2.*

Again, these black and white figures are actually full-color on your monitor, and each of the plotted lines are color-coded so you can easily determine what plotted lines are associated with specific numbers of ground hops. The Key in the upper-left-hand corner of the screen defines how many hops each of the colors represent. The angle of elevations can be read off of the vertical grid from top to bottom on the far left of the screen, where the propagation delay times were formerly determined in the last section.

In order to make optimum use of the ionosphere, it is necessary to orient your antenna so that most of the radiated power is transmitted at specific angles of elevation. Failure to do so limits how much control you have over *where* and *how far* your signals travel. In order for a signal to reach the ship at 36N 126W from Hawaii, it will be necessary to use one or more of the transmission angles of elevation shown in Figure 8.3.

Some people might have problems understanding how to read the plot in Figure 8.3 . To help in this regard, let's examine the single-hop line in Figure 8.3. This long plotted line covers frequencies from about 7 MHz up to the MUF of 23.5 MHz. It tells you that for single-hop paths, very low radiation angles of elevation between 0.0 and 3.0 degrees are required for signals to reach the ship at 36N 126W. In addition, there is a gap or void where no signals will be received (from one-hop signals), even with low-angles of elevation between about 14.25 and 16 MHz. Two-hop signals can only be received if the angle of elevation at the transmitter is between about 11 and 17 degrees above the horizon. Notice how only two-hop signals will be received between 14.25 and 15.25 MHz, as these are the only traces present. Between 15.25 MHz and 16.0 MHz, no signals are receivable at the ship. Both single-hop and dual-hop paths fail to reach the transmitter between these frequencies.

With this information in hand, you can determine what angles of elevation to use to exploit communications to remote locations using specific numbers of hops. You can also determine to some degree what type of antenna radiation pattern should be used. For example, for reliable single-hop communications, a very directional and narrow beam antenna will be required so that most of the radiated energy is emitted at angles of elevation less than about 4 or 5 degrees. Since most antennas in use today have a broader radiation pattern, it is reasonable to think that a fair amount of energy will be lost if only radiation angles between about 0 and 3 degrees reach the desired receiver in one hop. Such antennas are also more expensive and a bit more difficult to build. It might therefore be to your advantage to concentrate on 2-hop paths to the receiver, where the range of elevation angles required to reach the receiver are not as tight.

Using this information, you can construct antennas that avoid undue multipathing effects. For example, if an antenna was constructed to transmit most of its radiated power between elevation angles of 5 and 18 degrees, most of the radiated power would reach the receiver in 2-hops. The narrow transmission angles used would eliminate most of the multipathing interference that might occur with the single-hop, 3-hop, 4-hop, and 5-hop propagation modes, resulting in improved signal quality at the receiver.

Another way to use this information is to analyze how much multipathing might occur on specific frequencies with a given antenna. For example, an antenna that transmits most of its power between 10 and 30 degrees would see up to 3 propagation modes: 2-hop, 3-hop, and 4-hop propagation modes. To reduce multipathing effects and distortion, Figure 8.3 suggests that frequencies between 11.75 and 15.25 MHz should be optimum. The 3 and 4-hop MUFs are surpassed at 11.75 MHz and are no longer a problem, reducing multipathing substantially and improving signal quality. The 15.25 MHz upper-limit defines the 2-hop MUF. Frequencies above 15.25 MHz therefore will penetrate the ionosphere before reaching the receiver. Single-hop signals are not possible because the angles of elevation required to reach the receiver using the single-hop mode of propagation are not within the radiation pattern of the transmitting antenna. For these reasons, the 2-hop propagation mode is the desired mode for this antenna, path, and time of day.

Figure 8.4 is a similar elevation angle plot for the 5,300 kilometer path from Hawaii to Colorado. It was constructed using exactly the same data that was used to produce the plot in Figure 8.1. Also compare it with the shorter 3,500 kilometer path in Figure 8.3 and note the differences. Perhaps the most pronounced is the observation that lower angles of elevation produce more hops to the destination than for shorter distances. As well, the range of elevation angles required to support say six modes of propagation decrease as distance increases. For example, a radiation elevation angle pattern of 30 degrees is required to encompass all six possible modes of propagation on the 5,300 kilometer path, while the 3,500 kilometer path required a 42 degree elevation angle spread to cover six modes of propagation. The elevation angle spread between individual modes decreases as distances increase.

What does this all mean? It means that a fixed radiation pattern will begin supporting additional modes of propagation (and thereby perhaps introduce additional interference) as distance is increased. As well, in order to eliminate multipathing interference, transmitting antennas must become more directional, with sharper radiation patterns. Otherwise, signals will begin to travel using more than one mode of propagation and the receiver will (as a result) experience an increase in multipathing signal degradation.

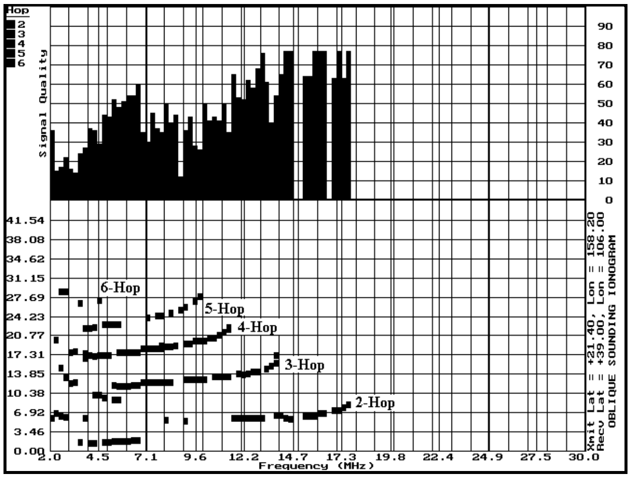


Figure 8.4: *Elevation Angle Ionogram from Hawaii to Colorado (5,300 km). Compare with Figure 8.1.*

Figure 8.4 shows that the MUF for the HF spectrum is associated with a 2-hop signal that is transmitted between elevation angles of approximately 6.0 and 8.0 degrees. If the transmitting antenna is incapable of concentrating energy below 8 degrees in elevation, then the 3-hop mode of propagation must be used. Notice that the 3-hop mode of propagation has a smaller MUF than the 2-hop mode. Frequencies above the 3-hop mode MUF would therefore not be received at all if the transmitting antenna failed to radiate power below 8 degrees. You would therefore be restricted to communicating on frequencies less than 14 MHz. These are important concepts which can be used to significantly improve communications between specific points.

8.4 Applying the Results

The foregoing discussion used the results of a night-crossing signal path from Hawaii to Colorado during geomagnetically quiet conditions and a low sunspot number. In this section, we will apply the knowledge given in the last several sections toward understanding propagation conditions that exist on a new path.

Let's consider the path from Texas (30N 100W) to the eastern U.S. (40N 75W) at 18:00 UTC (near local noon conditions) on 25 December 1991. The transmitter is in Texas. This corresponds to a geomagnetically quiet day (geomagnetic A-index of 7). The 12-month mean sunspot number for this date was 109. In addition, there were no flares or influential PCA present during this analysis.

Our antenna has a primary radiation pattern that extends from 0 degrees in elevation angle to about 50 degrees in elevation angle. We therefore used, as inputs to PROPLAB, a starting elevation angle of 0 degrees, an ending elevation angle of 50 degrees, and we used an elevation angle step rate of 0.5 degrees. In addition, we swept the HF spectrum using a starting transmitting frequency of 1.0 MHz and an ending frequency of 40.0 MHz with a frequency step rate of 0.25 MHz (250 KHz). The small step rates used increased the accuracy of the results, but required quite a few hours of computation time for the ray-tracing phase to finish. Nevertheless, the results are quite impressive and very informative.

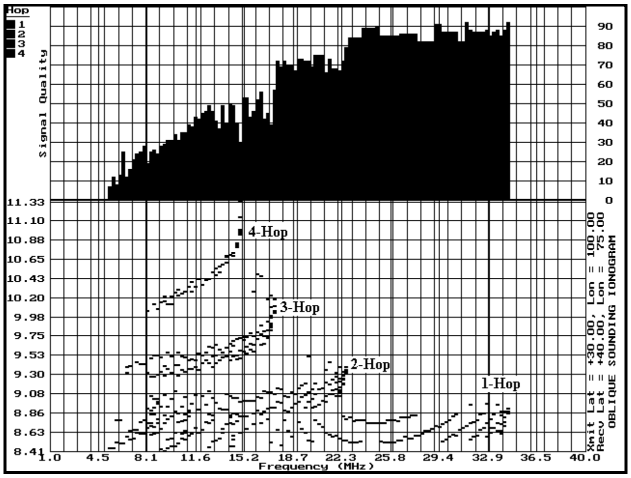


Figure 8.5: *Propagation Delay Plot for the path from Texas (30N 100W) to the Eastern U.S. (40N 75W), a distance of 2,520 km, on 25 Dec 1991 at 18:00 UTC.*

Figure 8.5 shows the results of the propagation-delay plot for this path. Immediately, several important parameters can be determined: the number of supported modes, the MUF of each mode, and the LUF of each mode. There are four supported modes of propagation: 1-hop, 2-hop, 3-hop, and 4-hop modes. The MUF's of each of these modes are: 34.25 MHz, 22.5 MHz, 17.25 MHz, and 14.75 MHz respectively. Similarly, the LUF of the 2-hop mode is 5.25 MHz, the 3-hop mode is 6.5 MHz, and the 4-hop mode is 8.0 MHz. The LUF for the 1-hop mode (from this figure) is difficult to determine since the traces for the 2-hop mode intermix with the 1-hop mode and cannot be discerned in these black and white renditions of the display screens. Suffice it to say that the 1 and 2-hop modes have similar LUFs in the lower HF band near 5 MHz.

The signal path from Texas to the eastern U.S. is a daylit path. The electron density within the ionosphere is therefore at its highest level. Signals must therefore be of a higher frequency in order to survive the strong D-region absorption which exists everywhere along this path. This is the primary reason why the LUF is higher than in the previous examples.

Consider now Figure 8.6, which shows the results of the elevation angle plot for the path from Texas to the eastern U.S.. This interesting plot differs from previous elevation angle plots presented, in that there are two sets of traces: one set for F-region reflections, and another set corresponding to E-region reflections. The small set of traces in the lower-left labelled "2-hop", "3-hop", and "4-hop" are E-layer reflections. The highly ionized state of the E-region during the day permits reflections from higher frequencies, provided the elevation angles are low. This figure then tells you that transmissions from Texas to the eastern U.S. can either be accomplished through E-region reflections on lower frequencies, or F-region reflections on high frequencies. This information was not clearly evident in Figure 8.5.

Let's try to choose a frequency which should have decent signal quality, low-distortion, and does not require very narrow antenna radiation patterns to achieve these results. The best signal quality is obviously associated with the single-hop high-frequency signals. If our antenna radiates a fair amount of power between about 5 and 8 degrees in elevation angle, the 1-hop

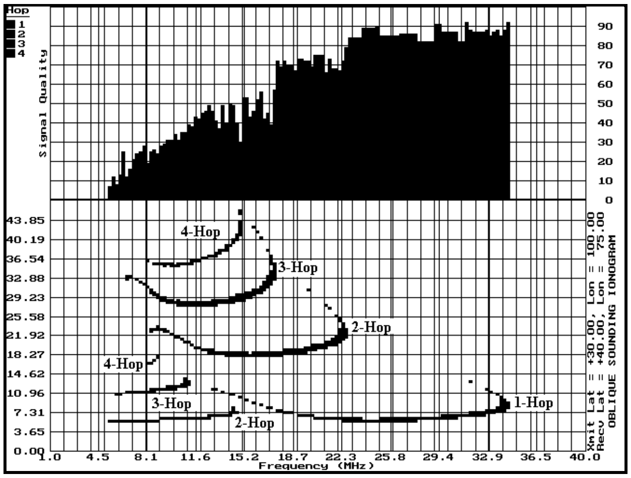


Figure 8.6: *Elevation Angle Plot for the path from Texas to the Eastern U.S. on 25 Dec 1991 at 18:00 UTC.*

propagation mode on a frequency near the FOT (0.85 x MUF) of 29 MHz should give the best results. However, as these figures illustrate, you have a fairly wide choice of frequencies before additional modes begin introducing significant levels of multipathing. Frequencies between about 23 MHz and 34 MHz will give good communications. Note, however, that if the MUF is approached too closely, severe MUF-fading could begin to be observed caused by the intermittent penetration of the signals through the ionosphere. A safer choice of frequencies would be between 23 and 29 MHz.

Notice how the traces in Figure 8.6 curve back in on themselves near the MUF. The lower trace (prior to the sudden curve at the MUF) represents the low-angle rays. Low-angle rays are relatively stable and are the most reliable rays to support communications. High-angle rays are much less stable, except near local-noon where the electron density does not change significantly, and usually are more difficult to sustain communications on. The high-angle rays are responsible for forming the upper curves in Figure 8.6 (curving from the lower-right to the upper-left) beginning at the MUF, or nose of the traces. High angle rays can be discerned in almost all of the supported modes of propagation except perhaps the 4-hop mode and the E-region reflections. Under some circumstances, the high-angle rays can support propagation on frequencies much higher than the basic MUF.

If the transmitting antenna radiates most of its power between elevation angles of about 5 to 35 degrees, with a primary direction of radiation at about 15 degrees in elevation, then our tactics must change. In this case, the usefulness of the 1-hop mode of propagation will be limited because most of the power radiated will not fall between the 5 and 8 degree elevation angle required to reach the receiver from Texas in one hop. However, *some* of the radiated power will likely be received at the receiver. But the signal from the one-hop mode will almost certainly be weak. For this reason, high-frequency communication above 23 MHz may be possible, but difficult. Given that the transmitter radiates most of its power at about 15 degrees in elevation, it would probably be wiser to use a frequency between 17.5 MHz (just above the 3-hop MUF) and 22.5 MHz (the 2-hop MUF), and rely primarily on signals reflected twice by the F-region for communications. Selecting these bounds for frequencies will result in minimal multipathing distortion. There will be some multipathing caused by weak 1-hop reflections, but most of the signal strength should come from 2-hop signals since the primary radiation angle is closer to that required for 2-hop propagation than for 1-hop propagation. Frequencies below about 17.5 MHz should probably be avoided, since they may be associated with more significant multipathing of greater than 2 milliseconds (examine the difference in propagation times between 2-hop and 1-hop propagation modes in Figure 8.5) caused by signals being received by both 1-hop, 2-hop, and 3-hop paths. Since our transmitter will not radiate much power above 35 degrees in elevation, 4-hop signals should not be observed which will limit signal multipathing to the 3-modes of propagation (1-hop, 2-hops, and 3-hops).

8.5 Commands Available While Viewing Ionogram Plots

There are several commands at your disposal while you view the ionogram plots produced by PROPLAB. These are summarized below:

Press "G" after the plot has been completed to save the screen image to the GIF-image file "IONOGRAM.GIF". You can then use GIF-image viewing software to view the saved image. The image will be saved according to the parameters established within PROPLAB's option menu (Main Menu option #8, suboption #17).

Press "P" after PROPLAB has finished plotting the ionogram to save the screen image in a PostScript compatible format for sending to a laser printer.

Press "H" after PROPLAB has plotted the ionogram to print the graphic screen to your printer. You must first edit the text printer control file "PROPLAB.PTR" before this function will work for your particular printer.

Pressing any other key will return you to PROPLAB's Main Menu. To re-examine (or redraw) the ionograms using different parameters, choose Main Menu option #1, suboption #4 (Generate Oblique Sounder Ionogram), and at the prompt to "Analyze previously generated ionogram data?", select "Y". This will transfer control back to the ionogram analysis utility and will let you reconstruct a new or different ionogram using different parameters.

SECTION 9 - COMPLEX AREA-COVERAGE MAPS

(Using the Complex Ray-Tracing Technique)

We use the term *complex* area-coverage maps to denote area-coverage maps that are created from results of comprehensive (or complex) ray-tracing sessions - that is, sessions which use the complex ray-tracing technique. It does not allude to the complexity of the maps. Producing area-coverage maps using the results of complex ray-tracing sessions is really quite easy to do.

To display area-coverage (or broadcast coverage) maps when using the comprehensive ray-tracing technique to trace rays, select Main Menu Option #6 and select the "C"omprehensive method.

The comprehensive broadcast coverage map generating utility is completely different from the software used to generate the simple broadcast coverage maps. This is primarily because the complex ray-tracing technique produces signal *strength* results as opposed to the signal *quality* values that the simple technique produces.

Before a broadcast coverage map can be displayed, data must obviously be collected by performing a ray-tracing session that uses the comprehensive ray-tracing technique. This is accomplished by first setting up the appropriate parameters in the Comprehensive Options Menu (Main Menu Option #8, Suboption #18, with emphasis on Choice #21) and then initiating the comprehensive ray-tracing function through Main Menu Option #1.

For best results, the option supporting the ability to ray-trace signals by sweeping elevation angles *and* frequencies *and* azimuths should be used, because this allows you to sweep in two directions (in elevation and across in azimuth), which simulates realistic transmissions. However, if you are only interested in single azimuths, you can produce results by sweeping only elevation angles (which keeps the azimuth constant). This has the advantage of showing you the effects of ionospheric tilts and non-great-circle propagation on specific azimuths.

The remainder of this section makes the assumption that you have already completed a ray-tracing session and are now within the utility to process the results into viewable broadcast coverage maps.

9.1 Types of Broadcast Coverage Maps Supported

The first menu presented by the comprehensive broadcast coverage mapping system software lets you select the type of quantity you want to map. The first choice (which is the default) lets you create a broadcast coverage map of the signal strengths of the rays that reached the ground during the comprehensive ray-tracing session.

The second type of map that is supported is a map of propagation delays (in milliseconds). This choice creates a map that shows you how long it takes signals to travel from the transmitter to the locations where the rays hit the ground. This may be used, for example, to help in determining multipathing that can affect digital communications.

The third type of map supported displays the maximum or minimum angles of arrival (elevation angles at the reception point where the ray reaches the ground). This is useful for determining the range of angles (with respect to the horizon) that signals are received. It can be used to help in the selection of appropriate reception antennas (for example, antennas that have maximum gain within the range of indicated angles of arrival).

The fourth type of map shows you the geographical locations where the rays reach the ground from the transmitter. It will display either ordinary or extraordinary rays (or both together). This type of map is extremely useful for observing how far signals deviate from great-circle paths. It can also be used to display the skip-distance from the transmitter more precisely than the contoured signal quality maps provide and should be used to more precisely determine locations where skip distance focusing may be occurring.

The last choice of the menu does not produce a graphical map, but rather displays the contents of the ray-tracing database file RAYOUT.DAT on-screen in a textual format. This can be very useful when you need to determine, for example, the precise signal strength (or other characteristics) of the ray that most closely approaches the receiver location or the characteristics of signals that have a *negative* signal strength (non-existent, in other words).

9.2 Type of Rays to Include

PROPLAB's broadcast coverage mapping system will analyze ordinary or extraordinary rays (or both types of rays) to produce coverage maps. At this prompt, select the type of rays you want included in the analysis. The default is to include both types of rays, as both ordinary and extraordinary rays are receivable by all antennas.

9.3 Specifying the Window Corner Coordinates of the Map

When PROPLAB produces a broadcast coverage map using the results of a comprehensive ray-tracing session, it builds a geographical map that includes all of the area covered by the great-circle path between the transmitter and receiver. It does this by computing a "viewing window" through which the results of the ray-tracings are presented.

PROPLAB asks you to type in the geographical latitude and longitude of the left corner of this window (either the left-top or left-bottom corner). It then asks you to type in the coordinates of the right-corner of the window (either right-top or right-bottom). The rectangular window formed from these two corners forms the basis for the viewing window. Any geographical details contained within the window are displayed.

Positive coordinates refer to northern latitudes and western longitudes. Negative values refer to southern latitudes and eastern longitudes.

9.4 Specifying Limits for Collected Data

PROPLAB will let you define specific *limits* to the data in the ray-tracing database. If a specific ray within the database falls within the acceptable limits you establish, the ray will be accepted and processed. If the ray falls outside of the specified limits, PROPLAB will ignore the ray and will not include it in the analysis.

The items which can be selected as limiting factors are known as *filters*. PROPLAB contains five filters which can be applied to the ray-tracing database. They are described below.

The "Elevation Angle" filter lets you specify the upper and lower limits for *elevation angles of arrival*. For example, to include rays which have angles of arrival between 7 and 30 degrees, you would specify an upper limit of 30 degrees and a lower limit of 7. Rays less than 7 degrees or more than 30 degrees will be excluded from the analysis.

Similar filters exist for rays with differing azimuths, frequencies, signal strengths and ground ranges. By specifying upper or lower limits on any of these filters, you can very selectively target sections of the ray-traced database for inclusion in the analysis.

9.5 Other Map and Contouring Options

The remaining prompts presented by PROPLAB are identical to those prompts given when constructing Global Ionospheric Maps. Consult that section of this manual for more information regarding these prompts.

A few side-notes are required with regards to the selection of the minimum contour to use. When generating signal strength maps or maps of minimum elevation angles (and possible other types of contoured maps), PROPLAB usually uses a minimum contour value of zero. This lets you determine where along the signal path signal strengths are zero or greater, etc. If the default of zero is used, PROPLAB may (while drawing the contours) plot small regions outside of the main zero contour that also contain zero contour levels. In other words, there may be satellite or island regions of contours labelled as zero. These small isolated island regions are a result of the pre and post-processing that occurs on the data to make it fit into the allocated map properly. They can (and should) be ignored. Alternatively, you can filter out these island regions by specifying a minimum contour value that is close to zero but is slightly positive (ex. 0.1 or 0.2). This will help clean up the display if you find it too messy.

9.6 Database Offset Value

The broadcast mapping software is only able to handle up to 2,000 datapoints at a time. That is, if you have traced more than 2,000 rays during a previous ray-tracing session, only the first 2,000 points will be used. By specifying filter limits, you can increase this number almost indefinitely by ignoring rays with certain undesirable characteristics. However, there is another way around this limitation.

The last question prompted by the mapping software asks you to specify an *offset* into the database. Normally, the offset is set at zero which means that PROPLAB will begin processing data at the very beginning of the database. By increasing this offset value, you instruct PROPLAB to begin skipping records in the database. If you have, for example, 3000 rays in the database (each ray occupies one record), then specifying an offset value of 1000 would force PROPLAB to skip the first 1,000 records in the database. It would therefore begin accepting data for analysis beginning with the 1,000th ray record.

Use this offset to analyze sections of your database that might not have been analyzed previously due to the size of your database.

9.7 The Plotted Map

After all of the prompts have been answered, PROPLAB begins reading in the database and filtering out those values which do not fit within the specified limits. The default limits should be more than sufficient to accept *all* of the data in the database. That is, if you do not specify or change any of the limits, PROPLAB will use the entire database.

After the data has been read, it is processed and the appropriate contouring matrices are established.

Following this (which will take some time depending on the resolution level you have selected and the speed of your computer), PROPLAB will clear your screen and begin plotting any geographical features that exist within the viewing window. This phase may also require a little bit of time since PROPLAB references the high-resolution geographical database of more than 100,000 coordinate pairs to create the geographical map. You can force PROPLAB to stop plotting the geographical features by pressing the ESCape key once during this phase.

PROPLAB now traces the great-circle path from the transmitter to the receiver. This is a useful reference line that can help determine whether or not signals are following or deviating from the anticipated great-circle path (and by how much).

The next step PROPLAB takes is to begin the contouring phase (if the map requires contouring). For maps which only plot the geographical locations where rays hit the ground, this step is skipped. All other maps begin the contouring. You can interrupt the contouring at any time by pressing the ESCape key once.

The map is considered complete after the map is titled at the bottom edge of the screen. When this occurs, you have several additional commands at your disposal. You can generate GIF or PostScript images of the screen by pressing the "G" or "P" keys respectively. You can send the screen to your dot-matrix printer by pressing the "H" key. Or you can return to the PROPLAB Main Menu by pressing any other key such as the ESCape key.

SECTION 10 - ANTENNAS

PROPLAB PRO Version 2.0 comes equipped with numerous types of antennas that can be immediately selected and put to work. Main Menu Option #10 places you in the antenna selection menu.

PROPLAB will also process custom-made antenna files that contain custom-built antenna radiation patterns. PROPLAB will *not* compute the radiation pattern based on the orientation of your antennas radiation elements. To do this, you must use other types of software.

10.1 Selecting Existing Antennas

From the antenna menu, scroll through the list by pressing ENTER until you find an antenna that most closely approximates your own. Then enter the number beside that antenna to select it.

The information presented beside each selectable antenna in the antenna menu gives important information about each antenna. The *maximum gain* figure describes the maximum gain of the antenna, relative to an isotropic radiator. An isotropic radiator is an antenna that radiates equal amounts of power in all directions. It therefore has zero gain because it spreads all of its power equally in all directions. Antennas that have measurable gain values create that gain by concentrating energy flux into specific directions. This requires energy to be sacrificed in other radiated directions. So antennas with large gains are usually highly directional. Antennas with low gains are more omnidirectional. The maximum gain value listed is given in units of decibels (or dB) above those of an isotropic antenna.

The *azimuth of maximum gain* describes the direction of the main radiation lobe of the antenna. For example, an antenna that has a maximum gain at an azimuth of 0 (zero) degrees means that the main lobe of the antenna points due north. This information is used by PROPLAB to determine gain figures at other azimuth angles during ray-tracings.

10.2 Displaying the Radiation Pattern

After the antenna has been selected, PROPLAB asks you if you want to display the radiation pattern of the selected antenna. If you answer "Y"es to this prompt, PROPLAB clears the screen and draws two graphical images on-screen. The image on the left describes the radiation pattern of the antenna as the transmission elevation angle (or takeoff angle) is increased from 0 degrees to 90 degrees. The image on the right describes the radiation pattern of the antenna in terms of the azimuthal angle from 0 degrees (true north) to 360 degrees (where 90 degrees points due east, etc).

You can save this graphical screen containing the antenna radiation pattern to a GIF or PostScript file by pressing the "G" or "P" keys respectively. You can print out the radiation pattern to your printer by pressing the "H" key. Any other key returns you to the Main Menu of PROPLAB.

All future ray-tracing operations (whether performed using the simple or comprehensive techniques) will reference the newly selected antenna.

10.3 Creating Your Own Antenna Radiation Patterns or Modifying/Deleting Existing Patterns

All of the antenna radiation patterns used by PROPLAB are stored in the subdirectory "ANTENNAS". Using a text editor, you can view or modify the contents of any of these radiation patterns.

To delete an existing radiation pattern so that PROPLAB can no longer use it, simply delete the required antenna radiation pattern file from the ANTENNAS subdirectory.

To create your own radiation pattern, copy the *template* file "BLANK.DAT" to another file of your choosing (remembering to keep the name of your new file uniquely different from the existing files so you don't accidentally overwrite an existing antenna radiation pattern). For example, to create a radiation pattern describing the characteristics of a *short wire antenna*, we could copy the antenna template file BLANK.DAT to a new file named "SHRTWIRE.DAT". Notice that the antenna radiation patterns must all have the extension .DAT. Failing to observe this requirement will make PROPLAB blind to the antenna file.

After we have copied the template file to our newly named antenna radiation pattern file, we can use a standard text editor to modify our new antenna file. Within each of the antenna files are specific key words (or acronyms) that are used by PROPLAB to define required parameters. Lines that are prepended with an asterisk are treated as comments and are ignored. The following acronyms are defined:

DESCRIPTION = Place your description of the antenna on this line, limited to 80 characters (which includes the word "DESCRIPTION:" which appears on the same line).

MAXANTENNAGAIN = The value placed directly to the right of this acronym defines the maximum gain of the antenna in the direction of *MAXGAINAZIMUTH* described below. The maximum gain given here must be given in units of decibels relative to an isotropic radiator.

MAXGAINAZIMUTH = The maximum gain of the antenna occurs in this direction, which is measured in degrees clockwise from true north. True north is therefore zero degrees. East is 90 degrees, west is 270 degrees, etc.

<u>*VGAIN*</u> = This acronym is used to mark the beginning of the values that describe the radiation pattern of the antenna in the vertical plane (that is, in elevation or takeoff angles). There must be 90 numerical values that follow the *VGAIN* acronym and each value must be on the *right-side* of an equal sign. The *left-side* of the equal sign must contain the elevation angle for which the gain value applies.

In actuality, the values following the *VGAIN* acronym are *loss* values that are <u>relative to the maximum gain of the antenna</u> (defined using *MAXANTENNAGAIN*). For example, if the maximum gain of an antenna is 24 dB and the *VGAIN* value entered at an elevation angle of 10 degrees is 20 dB, then the actual gain of the antenna at that angle of elevation would be only 4 dB (24 dB minus 20 dB). A value of zero dB would correspond to an antenna gain of 24 dB. A value of 30 dB would correspond to an antenna gain of -6 dB (or a *loss* of 6 dB). Be careful when entering radiation pattern values here. All values must be relative to the maximum gain of the antenna. It is therefore impossible to have *VGAIN* values that are negative, for this would imply that the antenna had gains that exceeded the maximum specified gain of the antenna, and this is not possible.

<u>*HGAIN*</u> = This acronym is used to mark the beginning of the values that describe the radiation pattern of the antenna in the azimuthal plane. There must be 360 numerical values that follow the *HGAIN* acronym. On each of these lines, there must be two values separated by an equal sign with the *HGAIN* value describing the signal strength gain (in dB <u>relative to the maximum gain of the antenna</u>) on the *right-side* of the equal sign and the azimuth on the *left-side*. Exactly the same procedure applies to these values as applied to the *VGAIN* values. Again, all values must be relative to the maximum gain of the transmitter as stated beside the acronym *MAXANTENNAGAIN* . Negative values are therefore impossible for the same reason as above.

After you have modified the antenna file, save it to disk and run PROPLAB. Then select the antenna from the antenna menu (Main Menu Option #10) and view the radiation pattern to make sure it is correct. If you can't find your antenna in the antenna menu, you probably saved your antenna file to the wrong directory. Make sure all antenna files are saved in the "ANTENNAS" subdirectory. PROPLAB will not search elsewhere for them. Also, make certain your antenna file has the extension ".DAT" (ex. SHRTWIRE.DAT). PROPLAB will ignore files that do not have this extension.

SECTION 11 - REAL-TIME MAPS

PROPLAB PRO Version 2.0 comes equipped with an exceptionally powerful new function that will produce *real-time* maps on your computer. You can even display the current local times for any number of cities around the world, all updated at user-specified intervals.

This function gives amateurs radio operators, for example, the ability to speak with friends on the radio while at the same time looking at real-time maps of ionospheric conditions, grayline locations and local times for cities around the world (including your friends local time). This is a significantly useful tool.

For this function to operate properly, a Plate Carree map must exist in your map library. If one does not exist, create one using the MAKEMAP utility. If you have more than one Plate Carree map in your map library file, you can select any of them to use here.

11.1 Setting the Gray Angle

The *Gray Angle* differs from the *grayline* in the following way. The grayline defines the regions of the world where the Sun is exactly zero degrees in elevation (that is, it is exactly on the horizon and is either rising or setting). The gray angle, on the other hand, defines the regions of the world where the Sun is a *user-specified* number of degrees in elevation above or below the horizon.

For example, to identify the regions of the world where the Sun is 20 degrees below the horizon (which, by the way identifies the ending of astronomical twilight), you would enter a gray angle of -20 degrees. Positive values correspond to elevation angles of the Sun that are above the horizon. Negative values refer to locations where the Sun is below the horizon.

PROPLAB will plot the gray angles corresponding to elevation angles between -60 degrees and + 60 degrees. A gray angle value of zero degrees coincides with the grayline.

11.2 Real-Time Global Ionospheric Maps

Perhaps the most powerful feature of PROPLAB's real-time mapping system is its ability to produce real-time global maps of ionospheric characteristics. PROPLAB will produce real-time maps of any of the mappable ionospheric characteristics described in the Section titled "Global Ionospheric Maps." In fact, many of the prompts which must be answered in that section are also required to produce real-time maps. Refer to the "Global Ionospheric Map" section for information on how to respond to the various prompts.

PROPLAB will produce real-time maps of ionospheric critical F2 layer frequencies, maximum usable frequencies for 3000 km (or variable-distance) paths, critical E-layer frequencies, M-factors for 3000 km distances, maximum heights of electron densities, solar zenith angles (which are 90 degrees minus the elevation angle of the Sun above the horizon - essentially solar elevation angles), and various maps of the Earth's magnetic field. PROPLAB will also produce real-time transverse plasma frequency maps of the ionosphere between any two points on the Earth. This latter map shows you a picture of the ionospheric layers and lets you see how the structure of the ionosphere changes in real-time. The magnetic field maps are not updated in real-time because their parameters change too slowly to observe (even over time-scales of years). For example, magnetic latitudes are related to the location of the geomagnetic poles and the poles only change minutely from year to year. Hence, mapping the geomagnetic field parameters in real-time is not really practical. All of the other maps, however, *are* updated in real-time.

11.3 Update Rates for the Real-Time Maps

The real-time maps displayed by PROPLAB can be updated at user-defined intervals of minutes. For example, the grayline can be updated once every minute if desired by specifying an update rate of 1 minute. Specifying an update rate of 0 (zero) minutes forces PROPLAB to continually update the display as quickly as possible.

For contoured maps such as maps of maximum usable frequencies, the timer starts ticking as soon as the map is finished being drawn. If your system requires several minutes to draw a contoured global map of maximum usable frequencies and you specify an update rate of 1 minute for these maps, PROPLAB will pause for one minute *after* it has finished drawing the map before it begins working on the computations to draw the next map after the 1 minute interval has expired.

11.4 Displaying Local Times for Cities Around the World

The local times for cities around the world can be displayed if a file by the name of "CITYTIME.DAT" exists in the same directory as the PROPLAB software. This file should describe cities (geographical locations and time-zone information) in the same format as the geographical location database file "PROPLAB.LOC". PROPLAB already comes loaded with a few cities in the CITYTIME.DAT file whose local times can be displayed in real-time as soon as you load up PROPLAB.

Since the CITYTIME.DAT file is in exactly the same format as the main geographical database file PROPLAB.LOC, if you want to include other cities in the CITYTIME.DAT file so that they are also displayed on-screen when you do real-time mapping, simply use your text editor to copy the lines containing the desired cities from the PROPLAB.LOC file to the CITYTIME.DAT file. Since these are both text files, modifying them or adding cities to them is as simple as loading your text editor and changing them.

To display *all* of the local times associated with the locations listed in the geographical database, use the DOS "copy" command to copy the PROPLAB.LOC file to the CITYTIME.DAT file. For example, type "copy PROPLAB.LOC CITYTIME.DAT". This will place a copy of the geographical database in the CITYTIME.DAT file. Now, every time you produce real-time maps, all of the local times for each of the locations defined in the PROPLAB.LOC file will be displayed on-screen and updated at the intervals you specify.

A prompt presented by PROPLAB in the real-time mapping function asks you if you want to display the *names* of cities on-screen as well as their local times. If you specify "Y"es here, PROPLAB will display the names of the cities above the dot which identifies the location for the city. The local time for that city is then displayed below the identifying dot. If you have a large number of cities to display, you might not want to include the names, because for large numbers of cities, the screen can quickly become saturated with city names that overlap one another. For a smaller number of cities, this can be useful to help you keep track of the city names.

11.5 Commands Available While Viewing Maps

There are several useful commands that are at your disposal while viewing maps in real-time. The standard screen-saving functions "G", "P", and "H" keys can be pressed to save screens to GIF format, PostScript format and to your local dot-matrix printer (respectively).

You can also use your mouse to set new transmitter and/or receiver locations. The method used to accomplish this is identical to the method of setting up the transmitter and receiver locations described earlier in this manual. Press and release the left mouse button to define the transmitter location. Then move the mouse pointer to the location of the receiver and press (and release) the right mouse button. The great-circle path, distance and bearing are then instantly displayed on-screen with X's marking the new locations for the transmitter and receiver. You can keep the transmitter fixed in location and change the receiver location by moving the mouse and pressing (and releasing) the right mouse button at each new desired receiver location. This is desirable if you have several reception points you want to examine from one transmitter.

***PLEASE NOTE* that PROPLAB does *not* change the actual location of the transmitter and receiver that is used by the rest of PROPLAB's modules. Changing the transmitter and/or receiver locations in this real-time mapping system module lasts only as long as you are in the real-time mapping system program. As soon as you return to PROPLAB's Main Menu (or to DOS), the original transmitter and receiver locations are restored.**

Two remaining commands that can be used while viewing the maps are the "+" (plus) and "-" (minus) keys. The plus key causes PROPLAB to increase the geomagnetic A-index by one point. The minus key causes PROPLAB to decrease the geomagnetic A-index by one count. This feature lets you adjust the ionospheric maps that may be dependent on geomagnetic activity (which applies to most of the maps except the geomagnetic ones). It is therefore possible to be running PROPLAB in the real-time mode and continuously adjusting the A-index every three hours when new geomagnetic activity values are broadcast by radio stations WWV or WWVH at 18 minutes past each hour on 2.5, 5, 10, 15, and 20 MHz. Incrementing the A-index values will also affect the location of the auroral zones, which will migrate southward and expand in size with larger geomagnetic A-indices.

With these commands at your disposal, it should be easy to see how useful the system could be for those who regularly communicate with others around the world (as amateur radio operators do). The ability to explore different paths, determine which ones cross into the auroral zones and by how much, as well as the changing ionospheric characteristics that occur along each path and the ability to see these changes in real-time, is an invaluable addition to PROPLAB!

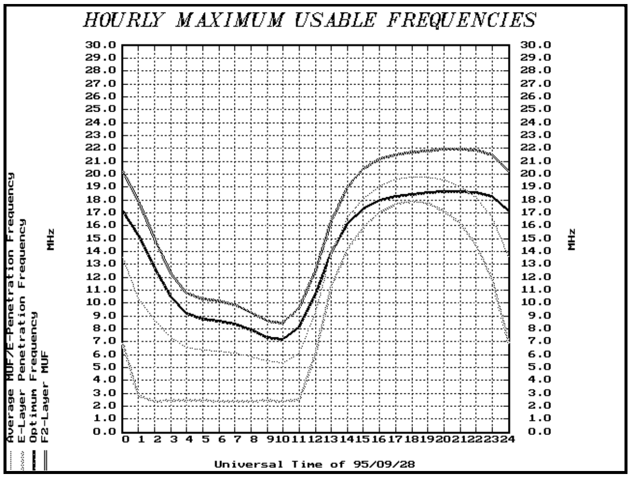
SECTION 12 - HOURLY MUF GRAPHS

Most radio propagation programs are capable of displaying the maximum usable frequency (MUF) as a function of time. PROPLAB is no longer an exception. PROPLAB PRO Version 2.0 will now compute and graph the maximum usable frequency between a given transmitter and receiver over a period of 24 hours. It will also graph several other important lines at the same time which will help guide the user into selecting appropriate transmission or reception frequencies.

The hourly MUF graphs are produced by using the simple ray-tracing technique to search for and locate MUFs and E-layer maximum usable frequencies. The E-layer MUFs are critical for determining the *lowest* frequency which will penetrate the E-layer. This is important for long-distance communications because long-distance communications can only be accomplished if the signals are reflected from the F-layers (which reside above the E-layer). Signals must therefore be high enough in frequency to punch through the E-layer but must also be low enough in frequency to be reflected by the F-layers and not penetrate them. These graphs are ideal for these purposes and give you a good idea when specific bands may open or close through the course of a day.

There are no required prompts to produce an MUF graph. The only parameters required are set within the Options menu (Main Menu Option #8). The transmitter and receiver locations, time of day and sunspot number or solar flux value are all that is required.

PROPLAB produces the MUF graphs by first collecting the MUF data for the given path for every hour of the day. Twenty-four MUF values are therefore collected. During this phase, PROPLAB shows you the UTC hour for which the MUF is being computed. It also displays the progress of the computations by plotting a period ("."), a vertical bar "|" and the letter "e". The period simply indicates that PROPLAB is busy working on the problem. For paths that are greater than 4,000 kilometers (and therefore require more than one hop), PROPLAB computes *two* MUF values at two separate control points spaced approximately 2,000 kilometers from each end of the path. These control points correspond to the path midpoints for one-hop distances 4,000 kilometers from each end of the path. When the first MUF is computed and the second MUF is about to begin being computed, PROPLAB prints the vertical bar. The "e" indicates that PROPLAB is busy computing the E-layer MUF for the control point in question.



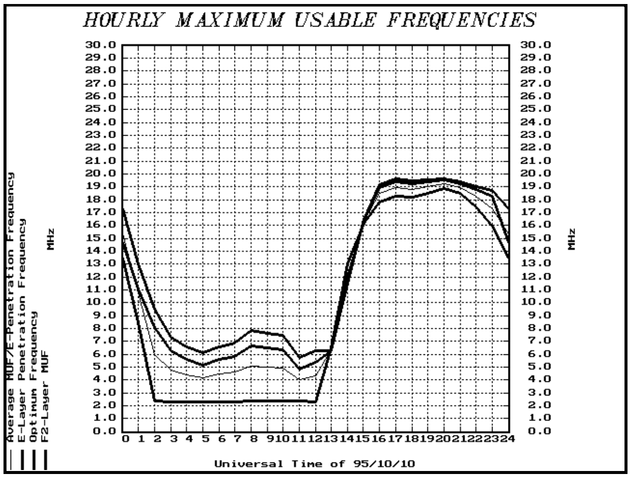
The Figure to the left shows an example of an MUF graph. The MUF of the F2 layer is the top-most line. The next line down is the Optimum Working Frequency (or FOT) and is 85% of the MUF. The thin line below the FOT is the numerical average of the MUF and the bottom line, which is the E-MUF (also known as the E-layer cutoff frequency).

For short-distance transmissions, frequencies should be kept *below* the E-layer MUF. If frequencies exceed the E-layer MUF, the signals will penetrate the layer and travel to the F-layer for reflection, which results in long-distance communications. This is desirable if you are only interested in long-distance communications where F-layer signal propagation is a must. In this case, the chosen frequency must reside between the E-layer MUF and the F-layer MUF. If the frequency you choose is above the F-layer MUF, the signals will penetrate the ionosphere and be lost to space.

The optimum working frequency (the FOT line) in the above graph is a line which tends to result in the most reliable communications (statistically speaking). However, there are often a range of frequencies near the FOT that can be used reliably. This range of frequencies is indicated by the thin line in the Figure above. This line is the average of the F-layer MUF and the E-layer MUF. The range of most useful frequencies is indicated by the spacing between the FOT line and this thin line. In the above example the FOT line tends to represent the upper-limit for useful frequencies while the thin line below it represents an estimated low-limit for useful frequencies. From about 11:00 UTC to 13:00 UTC, the distance (or range of frequencies) between the FOT line and the thin line decreases until they finally cross one another. This indicates a narrowing of the range of most useful frequencies. Between about 13:00 UTC and 21:00 UTC the FOT line represents the lower limit of optimum frequencies while the thin line represents the upper-limit. After they cross again shortly after 21:00 UTC, the thin line becomes the lower-limit and the FOT line becomes the upper-limit. In these ways, users can determine the most reliable range of frequencies at a given time during the day.

In addition to the sunspot number (or solar flux), time of day and the coordinates of the transmitter and receiver, PROPLAB also includes effects of enhanced geomagnetic activity through the geomagnetic A-index figure. A sample map given for the same path as the one above is presented below. The difference is the geomagnetic A-index is 100 (severe storm conditions). Notice the dramatic reduction in the MUF and how this effectively *narrows* the range of usable frequencies.

The time between approximately 13:00 UTC and 15:00 UTC shows a region where the



F2-layer MUF is *below* the E-layer MUF. This is significant because it shows that signals that penetrate the E-layer will *also* penetrate the F2-layer and be lost into space. Therefore, during that time interval F2-layer propagation is not possible and you would be limited only to E-layer propagation over shorter distances.

For most other times of the day, communications is possible via the F-layer only through narrow bands of frequencies. The width of the usable frequencies increases substantially during the night-time (from 02:00 to about 12:00 UTC). However, levels of noise and absorption will definitely be higher because of the depressed MUF values for that time period. Communications on the higher bands is not possible except during daylight.

While viewing the graphical results, you can press "G" or "P" to save the results to GIF or PostScript files respectively. You can also print the results on your dot matrix printer by pressing the "H" key. Press any other key to return to PROPLAB's Main Menu.

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