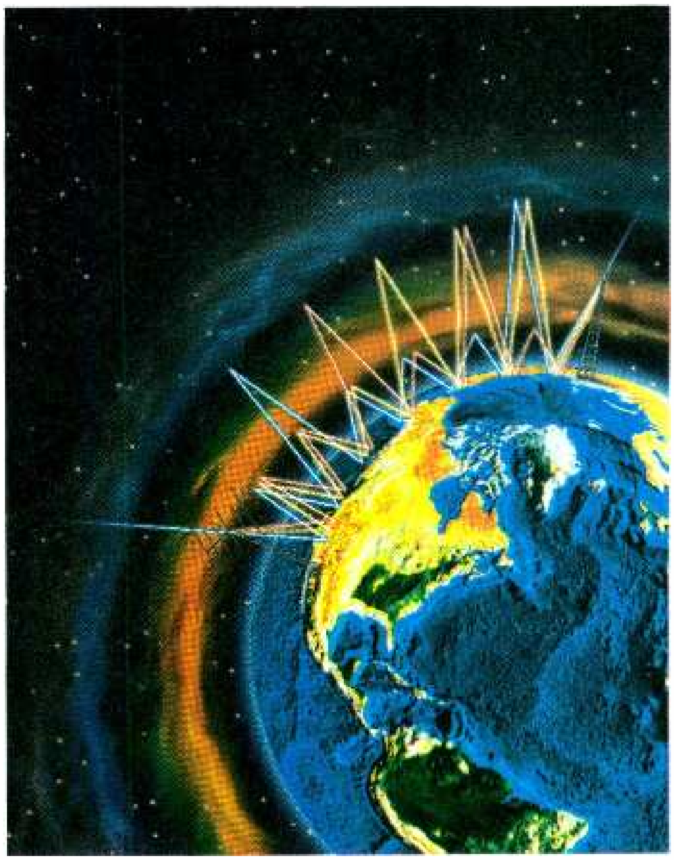


A BEGINNER'S GUIDE TO RADIO PROPAGATION

How do radio waves get from here to there? In this article we will present some of the basic principles of RF propagation and give pointers on how you can use this information as a radio amateur or SWL.

KARL T. THURBER, W8FX

Have you ever wondered why a signal generated several hundred or thousand miles away reaches your location without the aid of connecting wires? After reading this article you should have a pretty good understanding of how and why this is possible. In addition to discussing basic radio propagation principles and techniques, we will also cover the electromagnetic spectrum; the nature of radio waves; the regions of the Earth's atmosphere; sunspots and how the sun affects propagation; radio propagation modes and parameters; VHF and UHF propagation modes; using propagation charts and making forecasts; the role of personal computers (PCs) in forecasting; and sources of solar, geomagnetic, and propagation indices and data. Before we get into propagation details, let's start with what constitutes the electromagnetic spectrum.

The Electromagnetic Spectrum. The radio spectrum extends from a frequency of a few hertz (Hz), or 10^8 meters in wavelength, to about 300 gigahertz (GHz), or 1 mm (10^{-3} m). That is but a small part of the total electromagnetic spectrum, which extends to about 1 attometer (10^{-18} m), or a wavelength of one-quintillionth of a meter. Figure 1 shows the total electromagnetic spectrum in terms of increasing wavelength (or decreasing frequency).

Frequency-wise, those frequencies in the lowest portion of the spectrum (ranging from zero to 3 Hz) are known as ultra-low frequencies (ULF). Just above ULF lies another band called extremely low frequencies (ELF), which cover a range of 3 Hz to 3 kHz. Above that grouping, ranging from 3 kHz to 30 kHz, is the very low-frequency (VLF) range. Next are the low frequencies (LF), from 30 kHz to 300 kHz. The medium frequencies (MF) extend from 300 kHz to 3000 kHz (3 MHz).

From 3 MHz to 30 MHz are the high frequencies (HF). Above HF are the very high frequencies (VHF), from 30 MHz to 300 MHz. The ultra-high frequencies (UHF) extend from 300 to 3000 MHz, or 3 GHz. From 3 GHz to 30 GHz are the super high frequencies (SHF), and from 30 GHz to 300 GHz, the extremely high frequencies (EHF).

In this article, we'll be concerned with but a small portion of the total electromagnetic spectrum—covering long wave (LF) through the AM broadcast band and medium wave (MF), shortwave, VHF and UHF, and the microwave frequencies (low end starts at about 1 GHz).

The Fundamental Nature of Radio Waves. Radio communication is accomplished via electromagnetic waves, which travel through the Earth's atmosphere. Like light, radio waves are propagated as electromagnetic radiant energy.

Reflection, refraction, and diffraction, or some mix thereof, play an important role in radio-wave propagation. Reflection can occur at any boundary between materials with a different dielectric (non-conducting) constant. Radio waves can be reflected by ionized atmospheric layers, buildings, air mass boundaries, water, or the ground. Atmospheric reflection plays a large part in communication. Without an atmosphere, such as on the Moon or on other planets, we would not be able to enjoy the type of radio propagation we currently experience.

Refraction—the bending of radio waves as they pass at an angle from one medium to another—is common at boundaries between air masses; it is particularly noticeable at VHF, UHF, and microwave frequencies.

The term diffraction refers to the irregular spreading of waves due to interference of one part of the wave with another part. It also describes a change in the direction and intensity of radio waves as they pass by an obstacle or aperture. Diffraction is related to scattering—a "disordered" change in the direction of propagation when waves encounter matter, something like what happens when light tries to penetrate fog.

A practical way to classify radio waves is by propagation: ionospheric, tropospheric, or ground waves. Ionospheric waves (also known as sky waves) make up most of the transmitted electromagnetic radiation. HF radio waves are propagated as sky waves or ground waves, or a combination of both modes. Sky waves reflected from the ionosphere can traverse great distances, and enable global communication. Ground wave refers to signals that travel close to the Earth (though not necessarily touching it) and do not leave the lower atmosphere. Ground waves, which can include waves that follow the Earth's curvature by bending in the lower atmosphere or troposphere—a propagation form known as tropospheric bending—are not very useful for long-distance communication because they are greatly attenuated if they travel more than few dozen miles.

The term surface wave often is considered synonymous with ground wave, but, strictly speaking, the surface wave is a wave that travels in contact with the Earth's surface. Because of high attenuation, its propagation range is limited to about 100 miles or so, depending on wavelength and several other factors. Since attenuation increases with frequency, surface waves are of little value on HF. Such waves are most useful for low- and medium-frequency transmissions, such as the standard AM broadcast band.

The Earth's Lower Atmosphere. The Earth's atmosphere is the body of air surrounding the Earth, reaching elevations of more than about 500 statute miles. The atmosphere is divided into several regions or layers—the troposphere, stratosphere, and ionosphere. (There are other layers, but those listed are the ones with which we are most concerned.) Beyond the ionosphere lies the magnetosphere, as shown in Fig. 2. (All distances and distance conversions listed are approximate.) For the moment, we will concern ourselves with only the two lowest regions; the troposphere and the stratosphere.

The troposphere—which lies between the surface of the Earth and the tropopause (the region that separates the troposphere from the stratosphere and varies in height from about 5 miles at the poles to 11 miles at the equator)—is the lowest layer of the atmosphere. The troposphere plays a major role in VHF and higher frequency propagation. Immediately above the troposphere lies the stratosphere, a relatively calm region of the atmosphere that is located from about 5–30 miles above the Earth's surface. The stratosphere shows little temperature change throughout its height. About 99 percent of all atmospheric gases are found within the troposphere and the stratosphere.

The Upper Atmosphere. The ionosphere is divided into three major regions or layers: D, E, and F, in order of increasing altitude and electron density. Each layer plays a distinct role in ionospheric propagation, and each reflects or refracts radio waves depending upon the frequency and angle of arrival of the incident energy. The two lower layers of the ionosphere, the D and E regions, are absorbing layers, while the F layers are reflecting layers. The D layer—whose electron density is under direct solar control and in proportion to the sun's height or zenith angle—forms at from 30 to 55 miles above the Earth in daylight. The D layer peaks at about noon and mostly dissipates after sunset; it is also higher in summer than in winter. The D layer absorbs energy at the low end of the HF spectrum. The signal-strength reduction can be considerable,

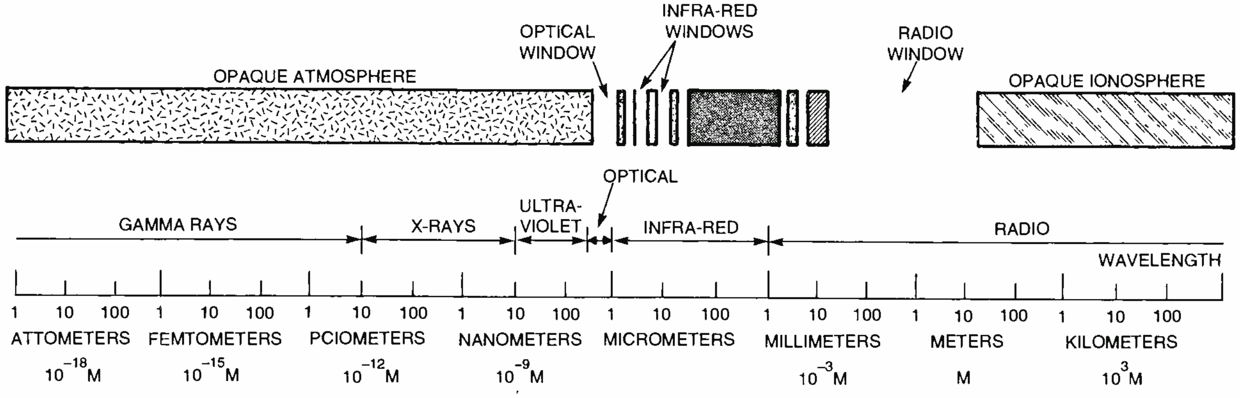


Fig. 1. The electromagnetic spectrum is an array of radiant energies. In order of increasing wavelength (smallest to longest) or decreasing frequency (highest to lowest), the types of electromagnetic radiation are gamma radiation, x-rays, ultraviolet radiation, visible light, infrared radiation, microwaves, and radio waves. The illustration shows the total spectrum in terms of wavelength and depicts the atmosphere's relative transparency—very important in understanding propagation concepts.

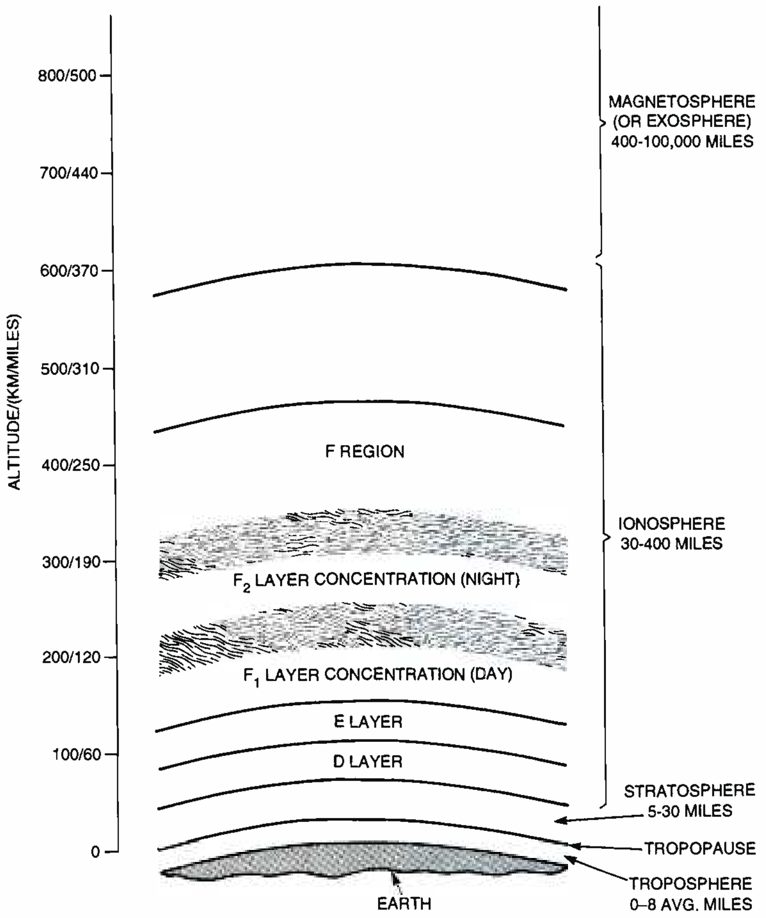


Fig. 2. Depicted here are the major regions of the Earth's atmosphere—ranging from the troposphere (the lowest region) through the stratosphere, ionosphere, and magnetosphere.

especially during daytime.

The E layer—the lowest layer that can refract HF signals—develops during the day at between about 60 to 70 miles above the Earth. It, too, is under strong solar control, with its ionization density reaching its maximum after noon and falling to a low nighttime level after sunset. However, the E layer does not completely disappear at night. The E layer has daily and seasonal variations that are similar to those exhibited by the D layer. Signals can propagate between two points via the E layer, as they do via the F layers. However, the maximum ground distance in one E-layer hop is only about 1200-1300 miles. Thus, more hops are usually required on DX paths. The DX, or long-distance HF communication, often is the result of both the F and E layers getting into the act in a variety of "mixed" propagation modes.

At elevations ranging between about 130 and 260 miles above the Earth's surface, the F layer is the highest ionospheric region. Long-distance HF communication is most influenced by F-layer ionization. In the daytime, the F layer splits into two parts: F_1 (at roughly 140 miles), and F_2 (at about 200 miles). At night and during the wintertime, the F_1 and F_2 layers recombine into a single F layer.

The F_1 layer, like the E layer, is under strong solar control and reaches maximum ionization about an hour after noon. When the F_1 region exists as a separate layer, its propagational effects are similar to those of the E layer. The F_2 layer is the highest layer. It usually has the highest electron density and is of great value in HF ionospheric propagation, but it is characterized by much variability. The height of the F_2 layer and its density depend on a variety of factors, including local time, season, sunspot cycle, latitude, and longitude. The maximum electron density of the F_2 layer usually occurs well after noon, sometimes even in the evening. The layer decays slowly at night. At mid-latitudes, the height of maximum electron density is higher at night than in the daytime, while at equatorial latitudes, the opposite occurs. The maximum Earth distance of one F_2 layer hop is about 2500 miles, readily enabling global communication via multiple hops.

While we're most concerned with the ionosphere, let us not forget what lies beyond—the magnetosphere, at roughly 400 to 100,000 miles above the Earth. This shell is an asymmetrical magnetic envelope which shelters the Earth from solar wind (a stream of ionized particles ejected from the Sun at high speeds) by deflecting it into space. The ionosphere lies closer to the Earth, but there is considerable coupling (both electric and magnetic) between these two layers.

How The Sun Affects Propagation. Solar dynamics have everything to do with propagation, just as they have a great deal to do with everything on Earth. The density and nature of the ionosphere is directly dependent on the amount of solar radiation that reaches the Earth. Sunspots are the sun's easiest-observed characteristic. (You may even have seen these dark spots or blemishes that appear periodically in groups on its surface.) They are probably caused by intense, localized magnetic fields trapped below the sun's surface. Sunspots are the source of flares, which are violent solar events that produce a variety of radiation, including high-energy particle cosmic radiation, low-energy particle radiation, and electromagnetic radiation, each of which has an effect on propagation.

Since the earliest days of observing solar activity, our measure of that phenomena has been based on counting sunspots. Radio propagation conditions vary with sunspot number and size, affecting both maximum usable frequency (which is the upper frequency at any given time for which a particular propagation path is possible) and signal absorption (which increases as the ionizing radiation increases). The sunspot number and solar flux are used as indirect measures of that radiation.

The International Sunspot Number (ISN) is used as an approximation of general solar activity. However, the ISN isn't just a simple count of visual spots, but instead involves a complex formula that takes into account other factors, such as sunspot grouping and size. The variation of ISN falls into well-documented long-term yearly patterns or sunspot cycles. The ISN can vary from near zero at sunspot minima to well over 200 at the peak. Most propagation models and programs require that the sunspot number be specified, while others let you use solar flux. Generally, the 2800 MHz (10.7 cm) solar flux, which varies from about 60 to 300, is considered to be a somewhat more dependable (yet still indirect) measure of radio noise coming from the sun.

Although both sunspot number and solar flux are used as activity measures, there isn't an exact mathematical relationship, especially if daily data is examined. But there is a fairly close correlation between the two if a 12-month running average (smoothed sunspot number, or SSN) for both sunspots and solar flux is used. Episodes of solar activity have a number of terrestrial effects. Ionospheric propagation is susceptible to several kinds of short-term disturbances, which upset the ionospheric electron configuration, thereby affecting propagation. The disturbances weaken signal levels and, in some cases, make them disappear entirely. A sudden ionospheric disturbance or SIDs—which can last from just a few minutes to several hours—or shortwave fadeout (SWF) occurs when x-rays emitted by a solar flare reach the sunlit portion of the D layer, increasing the electron density and absorption rate of that layer.

An event known as Polar Cap Absorption (PCA), caused by high energy protons from large solar flares, occurs as a result of intense ionization of the polar ionosphere. PCAs, which begin about 15 minutes to several hours after protons are ejected from the Sun, may last from about an hour to 60 hours or more. Ionospheric storms are caused by a variety of solar phenomena, such as coronal holes, coronal mass ejections, and solar flares. The storms last

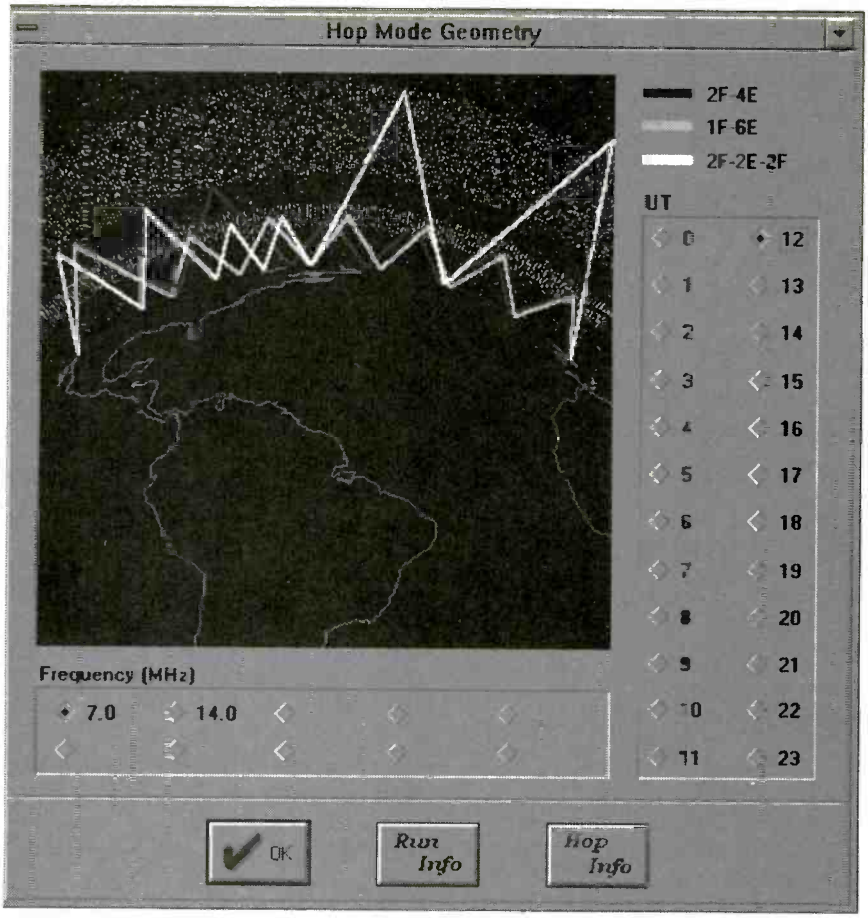


Fig. 3. Pacific-Sierra Research's HFx is a popular Windows HF propagation prediction program. The HFx Hop Mode model generates field strength, mode, availability, and signal-to-noise ratio (SINR) for a given date, transmitter and receiver pair, frequency, and antenna type. The program displays the data in several formats, including a graphic of sky wave ionospheric hops for each frequency at one-hour intervals, as shown here.

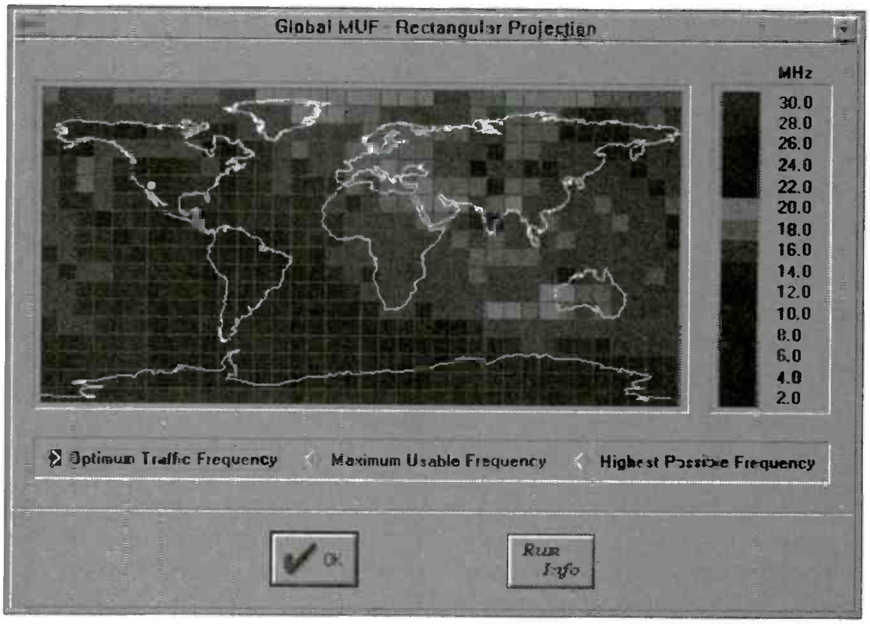
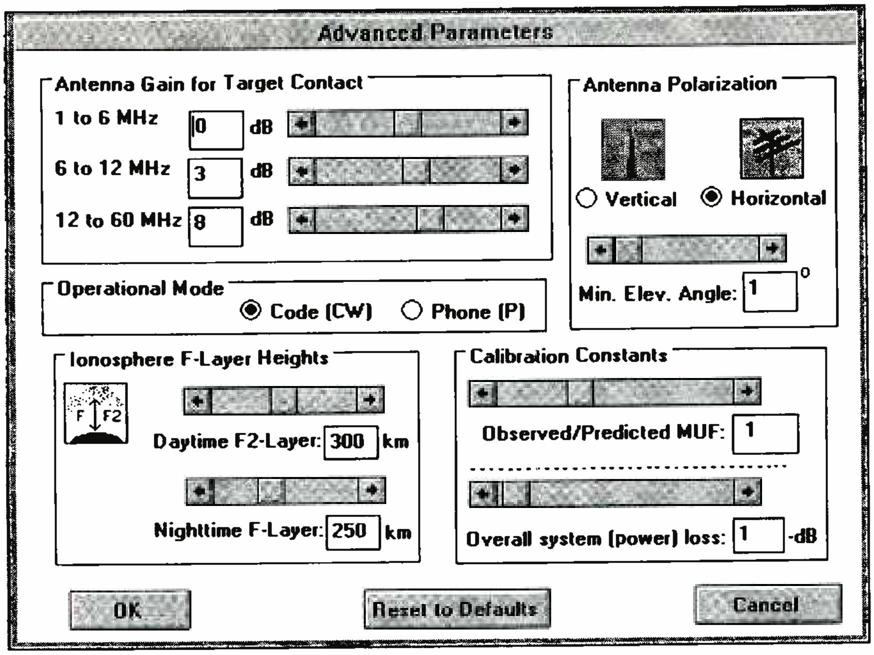


Fig. 4. The HFx Global MUF model generates a color map of Maximum Usable Frequency (MUF), Frequency of Optimum Traffic (FOT), or Highest Possible Frequency (HPF). Using this model, you can determine the best frequencies to reach any part of the world. Global MUF geometry is depicted here on a rectangular projection.



Antenna Gain for Target Contact
1 to 6 MHz: 0 dB
6 to 12 MHz: 3 dB
12 to 60 MHz: 8 dB

Antenna Polarization
○ Vertical ● Horizontal
Min. Elev. Angle: 1°

Operational Mode
● Code (CW) ○ Phone (P)

Ionosphere F-Layer Heights
Daytime F2-Layer: 300 km
Nighttime F-Layer: 250 km

Calibration Constants
Observed/Predicted MUF: 1
Overall system (power) loss: 1 -dB

Fig. 5. SKYCOM 2.0, from Fuentez Systems Concepts, Inc., is an easy-to-use Windows program that presents a "quick-look" prediction for "yes-no-maybe" contact possibilities; you can also obtain a detailed report. Shown here is the Advanced Parameters Window, where you can fine tune the program to better reflect prevailing conditions or set up "what if" scenarios.

from a few hours to several days, and some disturbances recur in step with the Sun's 27.5-day rotation on its axis. Although ionospheric storms are difficult to predict, they occur in conjunction with geomagnetic storms, so geomagnetic field disturbances are an indicator of ionospheric disturbances. Severity is indicated by the A and K indices included in the geophysical alert (Geoalert) broadcasts from the National Institute of Standards and Technology (NIST) radio stations WWV and WWVH. In general, maximum usable frequencies or MUFs decrease and absorption increases as geomagnetic field activity increases. Ionospheric and magnetic disturbances may be accompanied by visible auroras. Solar radiation is not constant by any means. There are both relatively short- and long-term solar cycles that must be dealt with.

Sunspot Cycles. The first solar cycle is short-term, based on the sun's own approximate 27.5-day rotation period, which can be observed visually by noting the periodic appearance of sunspots on the surface. Generally, sunspots reappear every 27.5 days, so that ionospheric propagation conditions tend to recur with that cycle. Since both geomagnetic activity and solar flux reflect the rotation period, you can make good short-term predictions for up to about a month in advance.

The number of sunspots reaches a maximum every 11 years (10.7 years to be precise), although the period varies from about 7 to 17 years. Cycle 19, which peaked in 1958, was the highest cycle recorded, with an average SSN of over 200. Experts generally agree that we passed through the trough or low point between Cycle 22 (which began in September 1986) and the current dawning Cycle 23, in mid-1996. Presently sunspots are again beginning their awaited climb, and DX conditions are starting to improve.

Long term predictions, such as deciding when a sunspot cycle has ended and another has begun, or even forecasting next year's conditions, is problematic. Doing so is a complex scientific endeavor that involves a variety of sophisticated techniques, all of which are beyond the scope of this article. Luckily, forecasting the next day's, week's, or month's radio conditions isn't all that difficult. The task has been simplified by easy-to-use propagation charts in popular radio journals, as well as some excellent computer software developed for that purpose.

High Frequency Communications. Most long-distance HF communication depends on the bending (refraction) of waves in the ionosphere, which consists of ionized regions caused by the Sun's x-ray and UV radiation. That ionization is intense enough to affect the properties of electromagnetic waves propagated through it. Upon entering the ionosphere, HF waves are refracted in proportion to the layer's ionization and the signal's wavelength. If the ionization is large enough, waves reaching the ionosphere are bent back toward the Earth as if they had been reflected, thereby enabling distant reception. However, there is a maximum frequency, at a given elevation angle, for which a transmitted signal will be refracted back to Earth. Higher frequencies, at the same elevation angle, penetrate this layer and may travel into space.

The highest frequency at which a wave is returned to Earth at vertical incidence (at ninety degrees or zero ground distance) is known as the vertical incidence critical frequency (or simply critical frequency). For communication between two points on Earth, vertical incidence serves no purpose—oblique propagation is necessary, and this method is directly related to the critical frequency. At transmissions above the critical frequency, the steepest angle at which a signal is reflected back to Earth is called the critical angle. Signals transmitted at angles greater than the critical angle pass through the ionosphere and *do not* return to Earth. Thus, depending on the critical angle and signal frequency, there is some distance beyond which there are no signal return, hence no sky wave. The area between the limit of ground wave range and the innermost edge of signal returned from the ionosphere is called the skip region (also known as the skip zone or dead zone), since sky wave signals simply skip over it.

The length of the skip zone is the skip distance—*i.e.*, the shortest distance that can be reached by a refracted wave at a given frequency, or the distance between the transmitter site and the ionospheric signal return. To reach shorter distances, you must use lower frequencies, although the signal may be heard weakly within the zone due to scattering effects.

Radio Propagation Modes and Parameters. Signals can travel from transmitter to receiver by one, two, or multiple hops. Propagation configuration modes can involve one or more F-layer (F_2) hops, one or more E-layer hops, or a combination of the two, with a ground reflection between adjacent hops. If the wave simply is reflected midway between points, it is referred to as one-hop mode. Two-hop mode is when the signal is reflected twice by the ionosphere and once by the ground. The reflecting layer can be the F_2 or the E layer—the E layer often is ionized sufficiently to reflect waves at low frequencies. Over long distances, different ionospheric conditions exist at each reflection point, so multiple hops can be quite complex.

Multihop paths that span the day/night boundary often involve a combination of E- and F-layer reflections, and are referred to as either F-layer modes, E-layer modes, or mixed modes. Recall that the maximum single-hop F_2-layer distance is about 2500 miles, while E-layer reflection is about 1250 miles; longer paths require multiple hops.

The range of frequencies that support communication between two particular points are of great interest to radio amateurs and shortwave listeners (SWLs). The MUF—which is influenced by absorption, transmitter power, antenna gain, receiver characteristics, type of service, and noise conditions—is the highest frequency at which a radio wave can propagate between two points at a given time by ionospheric refraction alone. Because of the great variability in the Earth's ionosphere, predicted MUFs on a given path aren't absolute values; rather, they are statistical. Predicted MUFs are median values: the actual value exceeds the predicted MUF 50 percent of the time; the other 50 percent of the time, it is less than that predicted. In general, transmission just below the MUF for a particular

FOR MORE INFORMATION

Suggested Readings

The ARRL Antenna Book, Eighteenth Edition, 1997. The American Radio Relay League, Inc., Newington, CT.

The ARRL Handbook for Radio Amateurs, Seventy-Fifth Edition, 1998. The American Radio Relay League, Inc., Newington, CT.

The ARRL Operating Manual, Sixth Edition, 1997. The American Radio Relay League, Inc., Newington, CT.

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Davies, K. *Ionospheric Radio*, 1990. Peter Peregrinus, Ltd., London, U.K.

Fiedler, LTC David M. and Ed Farmer, AAZM. *Near Vertical Incidence Skyware Communication*, Worldradio Books, P.O. Box 189490, Sacremento, CA 95818.

Jacobs, George, W3ASK, Theodore J. Cohen, N4XX, and Robert B. Rose, K6GKU. *The NEW Shortwave Propagation Handbook*, 1995. CQ Communications, Inc., Hicksville, NY.

Lee, J.G., W6VAT. *An Introduction to Radio Wave Propagation*, 1991. Bernard Babani Ltd., London, U.K. (distributed by Electronic Technology Today Inc., Box 240, Massapequa Park, NY 11762—reference publication BP293).

McNamara, L. F. *Radio Amateurs Guide to the Ionosphere*, 1994 Melbourne, FL: Krieger Publishing Co.

NIST Special Publication 432, *NIST Time and Frequency Services*. Boulder, CO. Time and Frequency Division, National Institute of Standards and Technology, June 1991.

NISTIR 5042-2, *NIST Time and Frequency Bulletin*. Boulder, CO: Time and Frequency Division, National Institute of Standards and Technology, February 1996 (published monthly).

NOAA Technical Memorandum ERL SEL-80, *A Radio Frequency User's Guide to the Space Environment Services Center Geophysical Alert Broadcasts*. Boulder, CO. Space Environment Laboratory, June 1990.

Pocock, Emil, W3EP. *Beyond Line of Sight: A History of VHF Propagation from the Pages of QST*, 1992. The American Radio Relay League, Inc., Newington, CT.

Thurber, Karl T., Jr. "Long Delayed Echoes: Fact or Fancy?" **Popular Electronics**, August 1995.

Names and Numbers

Here are the names, addresses, and telephone numbers for related products and services. Also included is contact information on several popular propagation prediction software programs (note the several programs with similar names)—information may be subject to change.

Collins Avionics & Communications Division, 350 Collins Road N.E., Cedar Rapids, IA 52498. Tel. 800-321-2223. (*PropMan* program).

Jacques d'Avignon, VE3VIA, 965 Lincoln Drive, Kingston, ON Canada K7M 4Z3. Tel. 613-634-1519. (North American distributor for the *ASAPS* program developed by IPS Radio and Space Services, P.O. Box 5606, West Chatswood, N.S.W. 2057, Australia).

Engineering Systems, Inc., P.O. Box 939, Vienna, VA 22180. Tel. 703-687-3000. (*Skycom*, DOS-based program).

Fuentez Systems Concepts, Inc., 11781 Lee Jackson Highway, Suite 700, Fairfax, VA 22033. Tel. 800-989-1447. (*SKYCOM 2.0*, Windows-based program).

Kangaroo Tabor Software, Rt. 2, Box 106, Farwell, TX 79325. e-mail: ku5s@wtrt.net. Web: *www.wtrt.net/~ku5s*. (*Wizard2*.Communications analysis prediction).

Pacific-Sierra Research Corporation, 2901 28th Street, Santa Monica, CA 90405. Tel. 800-820-4PSR. Web: *www.psrv.com/hfx/*. (*HFx* program).

Skywave Technologies (Jacob Handwerker, W1FM), 17 Pine Knoll Road, Lexington, MA 02173; Tel. 617-862-6742. (*IONSOUND* and *IONSOUND PRO* programs).

W6EL Software, Sheldon C. Shallon, 11058 Queensland St., Los Angeles, CA 90034. (*MINIPROP PLUS* program).

Xantek, Inc., P.O. Box 834, Madison Square Station, New York, NY 10159. Tel. 212-566-8240. (*Super DX EDGE* grayline computer program and slide rule based grayline calculator).

Websites

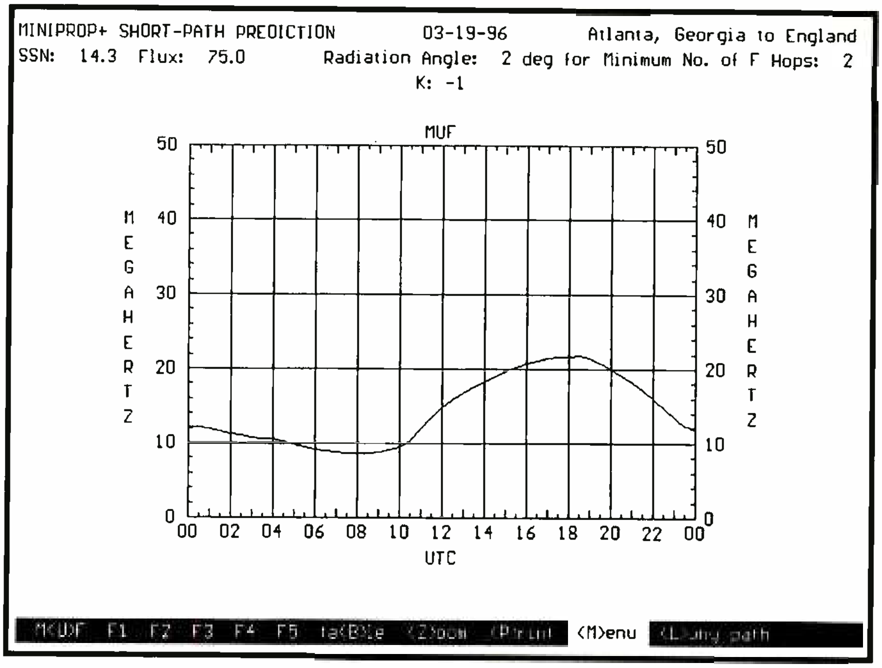
http://solar.uleth.ca/solar/—Solar Terrestrial Dispatch (in Canada), home page

www.dxlc.com/solar—for various solar activity reports (courtesy DX Listeners Club of Norway)

www.ngdc.noaa.gov—National Geophysical Data Center

www.sel.noaa.gov/—Space Environment Center

Also check numerous programs found on assorted ham-related bulletin boards.



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MINIPROP+ SHORT-PATH PREDICTION        03-19-96       Atlanta, Georgia to England
SSN:  14.3  Flux:  75.0      Radiation Angle:  2 deg for Minimum No. of F Hops:  2
                                        K: -1
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Fig. 6. MINIPROP PLUS 2.5 has significant graphical capabilities. Shown here a display of predicted MUF with a resolution of 30 minutes. The prompt line selections on the graph screen also allow you to view a graph of predicted signal levels or signal-to-noise ratio (S/NR) on each prediction frequency.

path produces the strongest signals. But for long paths, the true feasibility of communication is determined mainly by the MUFs of hops close to the transmitter and receiver. The MUF for the entire path is the lowest MUF.

There are also lower limits to useful communications frequencies over a given path. The lowest usable frequency (LUF)—which is determined by many of the same types of factors that govern the MUF—is the lowest frequency that is effective for ionospheric propagation between two points. If the LUF exceeds the MUF, you have a "radio blackout" and will probably be unable to maintain communication over the path.

The highest possible frequency (HPF) is often given in addition to the MUF. The predicted frequency supported by the ionosphere is higher than the predicted MUF 10 percent of the time. Ninety percent of the time the predicted frequency is lower than the MUF and is called the frequency of optimum traffic (FOT).

Unusual HF Propagation Modes. Here you have the basic modes of propagation; however there are some unusual propagation phenomena—such as F-layer grayline and long path propagation, non-reciprocal communication, ionospheric fading, auroral propagation, backscatter, sidescatter, and ducting, to name just a few—that may be encountered.

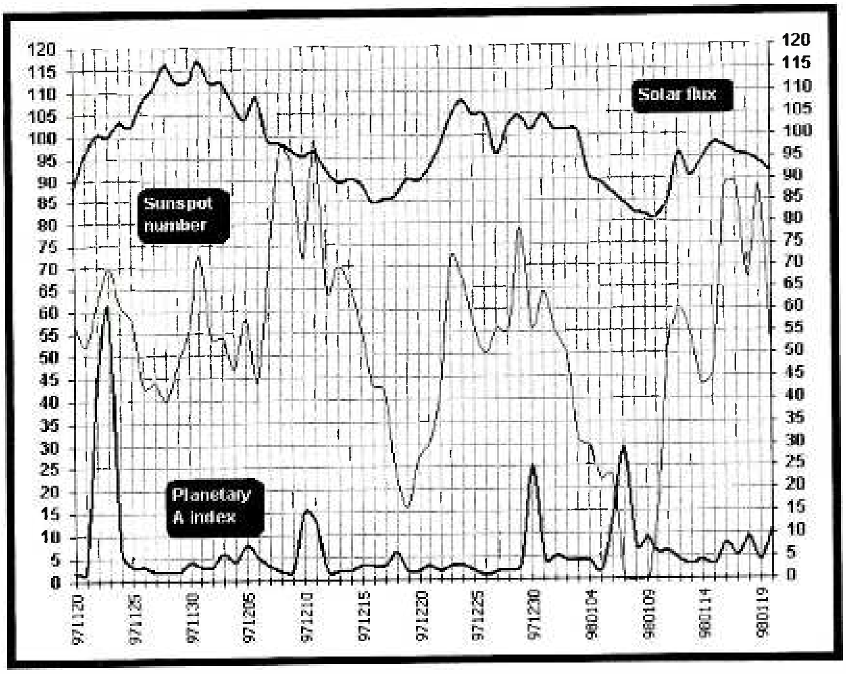
F-layer grayline propagation is a special form of propagation surrounding the unusual ionospheric configuration along the fuzzy "twilight zone" between day and night. The grayline (terminator), which generally runs north-south but can vary, extends completely around the Earth. Grayline propagation is very efficient, so it can be one of the best HF-communication modes, even with low power transmitters and modest antennas. However, at any given location, grayline conditions exist for only about two hours a day: when one station is in sunrise and the other in sunset (or *vice versa*)—one hour in the morning (plus and minus 30 minutes from sunrise) and one hour in the evening (plus and minus 30 minutes from sunset).

Usually, long-distance HF communication takes place along the shortest great circle path (the "short path") between points, which is always less than about 12,400 miles, or half the Earth's circumference. But you can sometimes make contact in the opposite direction, the long way around the Earth ("long path"). Although the great circle distance traveled by the radio waves may be longer, the absorption is less (due to the path traveled being in darkness). That type of propagation can be useful if the short path isn't open for communication. However, when both paths are open at the same time, you may hear an echo in the received signal due to the phase differences between the paths traveled by the incoming waves.

Normally, radio propagation is a two-way street. But because of atmospheric anomalies, especially differences in the junctions between ionospheric layers at the path ends, it is possible for signals to travel only one way over the path; that phenomena is called non-reciprocal communication, or one-way skip. It is more common to have a significant difference in signal strength at one end of the path, rather than the complete absence of the signal.

Ionospheric fading is the variation in signal strength caused by a gradual change in the nature of the transmission medium, where signals rise and fall over a few seconds to a few minutes. That phenomenon is usually caused by the interaction of several radio waves from the same source arriving (essentially out of phase) via different propagation modes. Stronger signals result from radio waves that arrive in phase and thus combine, while weaker signals are a result of out-of-phase signals arriving together. A variety of ionospheric phenomena can cause fading. Even signals arriving over a single path can fade due to changes in the ionospheric medium over the path.

Auroral propagation (aurora) is caused by sudden outbursts of solar activity wherein particles are ejected from the Sun. Some of those particles reach the Earth's atmosphere about 24 to 36 hours later, where they are channeled to the polar regions by the Earth's magnetic field. That causes a reaction with the Earth's magnetosphere and its magnetic field. The upshot often is a visible auroral display (the northern and southern lights) as well as a radio aurora—a sort of fluorescence of the E layer which tends to reflect radio signals above about 20 MHz.



*The solar terrestrial activity report (updated January 21 1998 at 0410 UTC)—downloaded (*www.dxlc.com/solar*) partially from data of the Sunspot Index Data Center in Brussels, and reproduced courtesy of Jan Alvestad.*

Backscatter—the scattering of a signal at the point where the ionospherically propagated signal arrives—helps to fill in skip zones. Sidescatter is similar, but the ground-scatter zone is somewhat off the direct line between the two stations. Both effects are particularly noticeable on the amateur 10-meter (28-MHz) band.

Ionospheric and magnetospheric ducting also may occur. In ionospheric ducting, signals may even become trapped in a duct (similar to a waveguide), possibly between the E and F layers, perhaps circling the world several times, traveling from one end of the ionospheric duct to the other. That phenomenon may be a major cause of so-called "Long Delayed Echoes" (LDEs) on HF signals. Ducting on VHF, UHF, and microwave signals may occur in the magnetosphere, rather than in the ionosphere, which largely is transparent to such higher frequencies.

VHF and UHF Propagation Modes. At one time people believed that communication on VHF and higher frequencies would be strictly line-of-sight, but that belief has been proven wrong. Many tropospheric and ionospheric modes and phenomena tend to make VHF and higher frequency propagation very exciting. Certain weather conditions can cause tropospheric refraction, producing greatly increased VHF and UHF signal coverage, and stronger signals than expected. The tropospheric phenomenon known as ducting takes place when refraction is so high that radio waves are bent back to the Earth. Ducting tends to occur when weather conditions involving temperature inversions are present.

All radio waves propagate at least partly through the troposphere, where they are subject to refraction, scattering, and other phenomena. While tropospheric conditions usually are not very significant below about 30 MHz, they're quite important at VHF and higher frequencies. You'll find a common but highly significant form of tropospheric propagation to be tropospheric scatter, sometimes called troposcatter. In fact, most VHF communication beyond the radio horizon out to about 300 miles is the result of signal scattering in the troposphere. One of the best features of troposcatter is that it is present most of the time, and it doesn't necessarily require special equipment—although high-gain directional antennas and high transmitter power are helpful.

The ionosphere's layers are most important at HF, but some ionospheric irregularities and modes are significant at VHF, especially in the range 30–100 MHz. One of these is D-layer ionospheric forward scatter. That mode is fairly uncommon and usually causes weak signals, but it can produce VHF communication of up to about 1000 miles. It is most noticeable when other forms of propagation aren't present.

Embedded at times within the E layer is the sporadic-E layer—an anomalous ionization layer that is sometimes patchy and irregular and, at other times, as smooth as silk. Many experts believe that intense sporadic-E ionization is caused by wind shear. Sporadic-E layer properties vary greatly with latitude and time of day. "Short-skip" openings on the amateur 6- and 2-meter bands often result from one-hop sporadic-E ionization.

Another E-layer propagation phenomenon is auroral E, which is noticeable on the amateur 28-, 50-, and (sometimes) 144-MHz bands. It is common across the northern third of the US and southern Canada at about the same time as auroral activity is diminishing. Signals, much like sporadic-E, sometimes have a "hollow" sound. Effects are found mostly on east-to-west paths over distances up to about 1400 miles. Auroral E openings usually last for an hour or two.

F-layer trans-equatorial spread-F, sometimes known as trans-equatorial (TE) propagation—possibly due to irregular "bulges" in the F_2 layer near the equator—can result in signals propagating between 3100 and 5000 miles across the equator; the signals tend to move westward with the setting sun. The effects have been noticed as low as the 10-meter amateur band and as high as 432 MHz. Trans-equatorial signals have a rough, auroral character, sometimes called "flutter fading," which some texts describe as trans-equatorial field-aligned irregularities.

Large numbers of meteors, or "shooting stars," enter the atmosphere every day. The number increases at certain periods of the year during "meteor showers." The larger meteors leave a long, ionized trail behind them, especially prominent in the E layer, which allows the reflection or scattering of VHF signals. Meteor-burst openings affect VHF to 200 MHz signals or higher traveling at altitudes between 300 and 1450 miles. You'll find meteor scatter contacts usually very short. It is not too difficult to literally bounce VHF and higher frequency signals off the moon (over what are known as Earth-Moon-Earth, or EME paths) across a wide range of VHF, UHF, and microwave frequencies. In fact, it's been done by amateurs since 1960 (1953 if you count "one-way" EME echoes of an amateur's own signals). Since the moon reflects only a few percent of the signal that reaches it, high-power and high-gain antennas on both ends generally are needed for success.

Using Propagation Charts And Making Forecasts. All this knowledge is little more than academic esoterica unless you have some idea of how to convert theory into practice. Amateur-radio operators, SWLs, VHF/UHF scanner buffs, and others are all interested in predicting ionospheric radio conditions. An easily-obtained solar flux or sunspot number is all that's needed to plug into a propagation prediction program to see when and if the band(s) will be open to a given location. Some like to keep up with expected conditions via the propagation column of their favorite amateur radio magazine. Still others like to have the raw data to "roll their own" propagation estimates.

However, predicting propagation conditions is something like predicting the weather—it is not an exact science. Particularly daunting is that the underlying phenomena and relationships are complex and involve many variables. Experience and a knowledge of predicted and actual propagation conditions are required to make realistic and useful forecasts.

Luckily most of us focus on practical, short-term forecasting, since it's impossible to accurately predict propagation conditions far ahead. We're interested in whether today or this week or this month is going to give us conditions good enough to warrant participating in a DX radio contest, or we want to know what time of day we're likely to hear or "work" a DX station. Several vehicles exist for doing this.

Direct observation, although not really forecasting, is a technique that requires you to scan the band(s) of interest to see what DX is rolling in, and where it is coming from. It is similar to the meteorologist looking out his window to check the weather. That method is fine as a real-time technique and for extrapolating very near-term conditions, but reveals little about radio conditions in a few hours or days. Direct observation works well for real-time SWLing (provided that you know which stations from which areas should be on the air at a given time). However, that technique has a disadvantage for radio amateurs. For hams, conditions might be open to particular areas of the world, but no one is transmitting from them. Thus a band may appear "dead" when it's really just dozing.

A more polished form of direct observation involves systematically scanning known operational HF beacon stations in various areas of the world. A variety of organizations operate beacons, which are mostly clustered on the 10- and 20-meter amateur bands; many are on 6 meters. For example, the Northern California DX Foundation (NCDXF) operates a network of beacons on 14.100 MHz in the 20-meter band, and the International Telecommunication Union (ITU) operates beacons in Australia and Norway on frequencies adjacent to several HF amateur bands.

Using Computers In HF Propagation Prediction. Until recently, radio hamshack and SWL PC software was focused mainly on QSO (contact) and contest logging. Today, however, software has been developed that lets your PC perform many other chores, and most can be customized for your QTH. You can even produce timely predictions of sky wave conditions (or MUF) between any two points. Some programs can handle such chores as estimating LUF and other propagation parameters such as HPF and FOT, as well as signal strength, signal-to-noise ratio (S/NR), number and configuration of hops, long- and short-path distance and heading, radiation angle, time zones, and other parameters.

Pacific-Sierra Research's *HFx* is a popular *Windows* HF propagation prediction program. The HFx Hop Mode model generates field strength, mode, availability, and S/NR for a given date, transmitter and receiver pair, frequency, and antenna type. The program displays the data in several formats, including a graphic of sky wave ionospheric hops for each frequency at one-hour intervals, as shown in Fig. 3.

. The HFx Global MUF model generates a color map of maximum usable frequency, frequency of optimum traffic, or highest possible frequency, as shown in Fig. 4. Using this model, you can determine the best frequencies to reach any part of the world. Global MUF geometry is depicted here on a rectangular projection.

SKYCOM 2.0, from Fuentez Systems Concepts, Inc., is an easy-to-use Windows program that presents a "quick-look" prediction for "yes-no-maybe" contact possibilities; you can also obtain a detailed report. Shown in Fig. 5 is the Advanced Parameters Window, where you can fine tune the program to better reflect prevailing conditions or set up "what if" scenarios.

MINIPROP PLUS 2.5 has significant graphical capabilities. Shown in Fig. 6 is a display of predicted MUF with a resolution of 30 minutes. The prompt line selections on the graph screen also allow you to view a graph of predicted signal levels or signal-to-noise ratio (S/NR) on each prediction frequency.

Summary. We have covered some of the more basic aspects of radio wave propagation: the electromagnetic spectrum; the nature of radio waves; the regions of the Earth's atmosphere; sunspots; propagation modes; the role of personal computers in forecasting; *etc.* This primer wasn't intended to make you a propagation pro, but with the information we've presented, you should be well on the way to understanding how propagation works and making the most of your newfound skills. ■