PROPAGATION

After reading Part II, the mysteries and frustrations of 160 meter operation may not vanish totally, but the clouds will have lifted and you will have a new understanding of how Topband works.

The 160 Meter Band

An Enigma Shrouded in a Mystery—Part II

BY CARY OLER*, AND DR. THEODORE J. COHEN**, N4XX

In the March 1998 issue of *CQ*, CaryOler and Ted Cohen, N4XX, introduced us to some of the phenomena responsible for the unusual radiowave propagation we observe on the 160 meter band. Included were discussions of D-region absorption, the electron gyrofrequency, the auroral oval, and secondary effects caused by sunspot activity. This month they conclude their two-part presentation with a discussion of ionospheric ducts, tips for improving your Topband DX operations, computer software tools, and a host of other information of interest to both Topbanders and HF enthusiasts alike. Taken together, this two-part series provides the single, most detailed exposition on Topband radiowave propagation ever published in the amateur radio literature.—*K2EEK*

DXing By Means of Ionospheric Ducts

You may not realize it, but a considerable number of DX openings on Topband over distances greater than 4,000 kilometers may owe their occurrence to a phenomenon known as *signal*

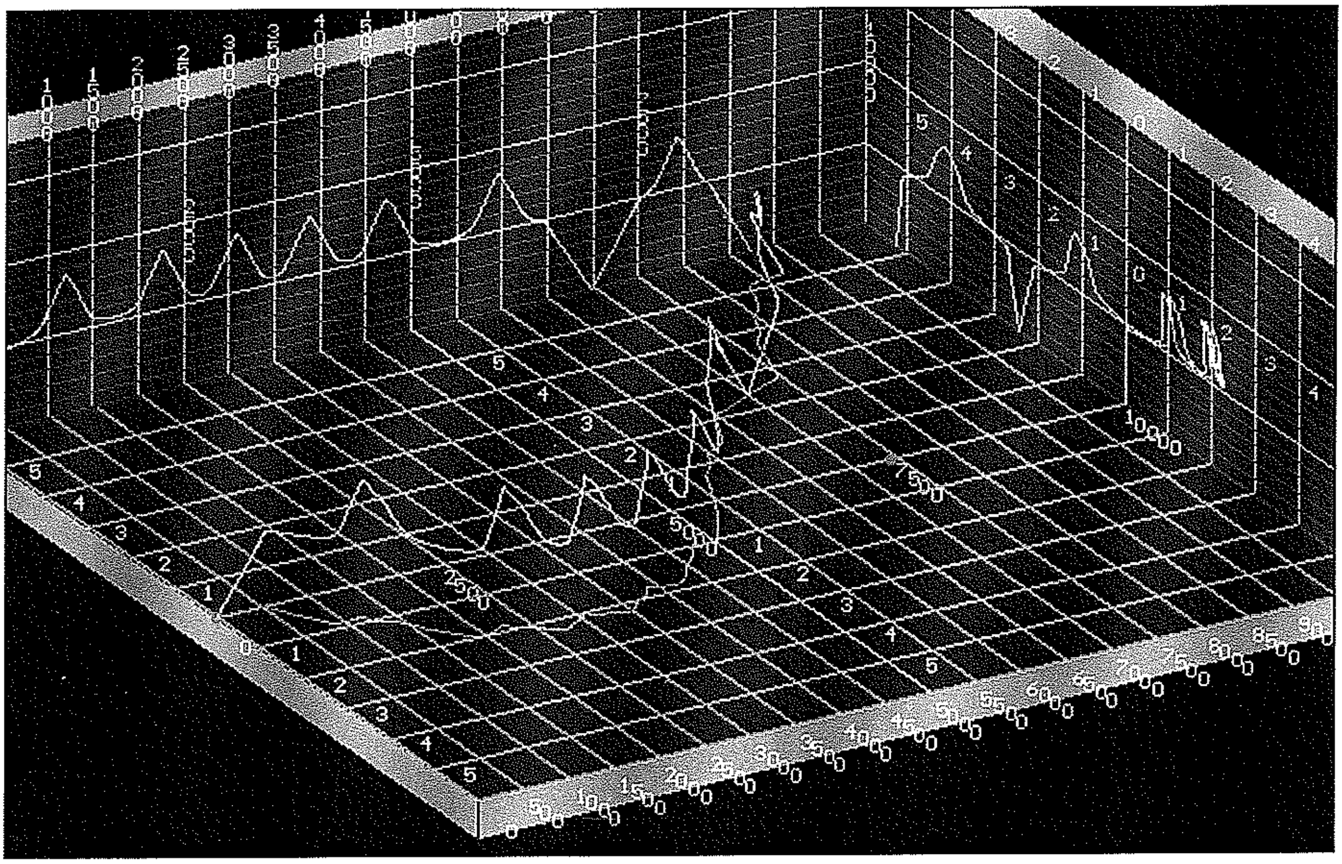


Fig. 5– A ray-traced example of how a 160 meter signal ducted from Washington, D.C. (left-hand green dot) toward Hungary (right-hand green dot) on a night in December during very quiet geomagnetic conditions. The altitude of the signal is shown by the "wall" in the upper-left corner (each line on the wall is separated from each other line by 20 kilometers). The deviation of the ray away from the great-circle path (in kilometers) is shown on the other wall at the top to the top right. The great-circle path is the line connecting the two dots on the base of the three-dimensional grid. Notice how the signal skews northward and southward of the great-circle path as well as the twisting of the ray as it travels through the ionosphere.

---

*Solar Terrestrial Dispatch, P.O. Box 357, Stirling, Alberta, T0K 2E0 Canada (e-mail: <Oler@Solar.Uleth.Ca>
**8603 Conover Place, Alexandria, VA 22308

ducting. A ball thrown into a narrow tunnel will bounce around the walls of the tunnel while maintaining its general direction of travel. In essence, it is "ducted" through the tunnel. Similarly, a radio signal that is "shot" into an ionospheric "tunnel" will duct between the walls of the tunnel until the walls either disappear or become weak enough to permit the signal to break through. The walls of an ionospheric "tunnel" are the edges of the ionospheric layers. The D-region is normally insufficiently ionized to allow radio signals in the MF and HF bands to duct. However, the increased electron densities in the E- and lower F-regions are sufficient for Topband signals to be ducted *if* they can enter these regions at just the right angles and *if* the right conditions exist.

One such example of ducting, shown here in fig. 5, was visualized by simulating what happens to a signal as it travels into and through the Earth's ionosphere. This figure shows the path the ordinary (primary) component of a 1850 kHz radio signal takes as it travels from Washington, D.C. to Hungary in December under quiet geomagnetic nighttime conditions. The transmitter (Washington, D.C.) is identified as the green dot on the left-hand side of the three-dimensional graph. The receiver (Hungary) is located just under 7,500 kilometers away (see the associated green dot). The line connecting these two green dots (labeled with the number zero) represents the great-circle path from Washington, D.C. to Hungary. The "wall" at the top and left part of the figure shows the altitude of the signal above the surface of the Earth (each line on this wall is separated by 20 kilometers in altitude). The wall on the right side shows the deviation that the signal takes *away* from the great-circle path, in kilometers. The signal itself starts at the Washington, D.C. green circle and travels at a 10 degree takeoff angle toward the ionosphere. The *ground-track* of the signal can be seen on the base of the three-dimensional plot. It stays precisely on the great-circle path until the signal reaches the base of the ionosphere. It then abruptly pulls equatorward (due to magneto-ionic splitting of the signal into *ordinary* and *extraordinary* components) about one kilometer from the great-circle path as it traverses through the D-region. The signal encounters its greatest absorption as it transits the D-region.

At this particular take-off angle, the signal is refracted and bent just enough to allow the signal to begin ducting between the base of the F-region and the top of the E-region, within what is known as the *E-valley region*. Because this region of the ionosphere is in darkness, it is fairly stable and allows the ducting to continue unimpeded for almost 6,500 kilometers—a respectable distance, indeed.

Notice the crooked path of this signal. **It does not precisely follow the great circle path, but deviates northward and southward according to changes in the shape of the ionospheric layers and the orientation of the signal to the Earth's magnetic field through which it is being ducted.** (Most Topband operators who have multiple, directional receiving antennas (e.g., Beverages) will tell you that the signals from distant stations often arrive on azimuths off the great-circle path.) Finally, about 6,500 kilometers from Washington, D.C. the E-region is no longer ionized sufficiently to refract the signal back to the base of the F-region. Therefore, the signal breaks out of the duct and travels back to the Earth's surface. In doing so, it crosses through the absorbing D-region a second time. It then bounces back into the ionosphere and completes one more hop before the simulation ends. A close examination of the signal near the end of its path (where the signal begins moving almost directly away from our line of sight) shows the very odd behavior of a top-band signal. It is not straight and linear as you might expect. Indeed, it suffers from kinks and twists that can change the angle of arrival of a signal as well as its direction and polarization characteristics. This is typical behavior for Topband signals, and it is the result of the signal's close proximity to the electron gyrofrequency. The situation gets even worse as the carrier frequency more closely approaches the gyrofrequency.

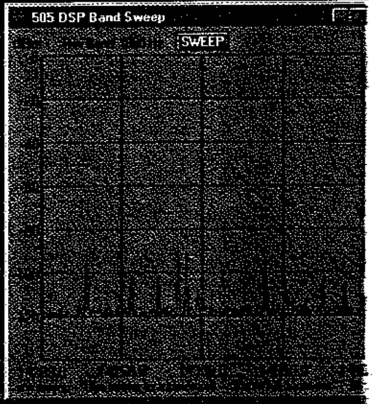
Our intended recipient in Hungary never heard this signal because the signal fell short of the receiver by about 500 kilometers. Instead, a fellow Topband operator in Czechoslovakia heard the signal loud and clear. If his transmitter and antenna were capable of transmitting enough radiated power at the right angle of elevation required for the signal to enter this same duct, it would begin ducting right back to the operator at Washington, D.C., thereby permitting a two-way conversation.

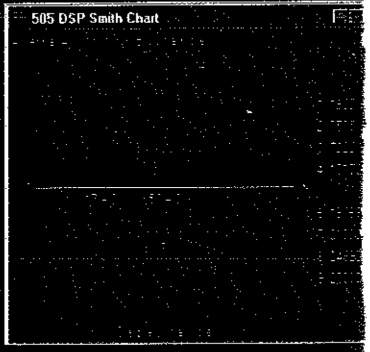
The strength of this 1850 kHz signal received in Czechoslovakia would have been fairly strong because the signal only crossed through the D-region two times—once when it left the transmitter at Washington, D.C., and again after ducting for almost 6,000 kilometers. It also did not suffer a passage through the auroral zone, but instead passed under it thanks to the very quiet state of the geomagnetic field. **This mechanism probably accounts for the inability of a given station to hear a DX signal that fellow operators only a few hundred kilometers away are copying with exceptional strength.**

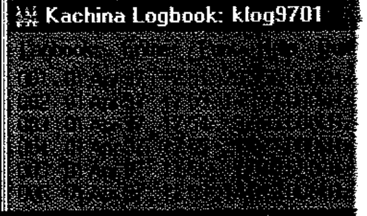
Ducting of 160 meter signals is more easily (and more frequently) accomplished than is ducting at shorter wavelengths, because the top-band signal can be refracted to a much greater extent at higher angles of elevation than can signals at shorter wavelengths. Stated another way, Topband signal ducting is most likely to occur when transmission elevation angles of between about 5 to 30 degrees are used. At shorter wavelengths (e.g., 80 to 20 meters), most signals need to be transmitted using shallower angles of elevation of between 0 to 15 degrees to enter the main ducting regions. However, since most amateur antennas can't radiate sufficient energy at transmission elevation angles much lower than about 10 degrees, the total signal energy that enters the duct at higher frequencies will be much lower than the energy emitted into a duct by a 160 meter antenna at Topband frequencies. The end result can be higher signal strengths from 160 meter ducted signals.

Some ducts are very sensitive to changes in ionospheric conditions, take-off angles, and changes in antenna azimuth. This explains why some DX openings are short-lived or change rapidly with time, or are of poor quality. Other ducts are less sensitive to changes, and they may be quite stable for hours and extend over broad ranges of signal azimuth and elevation.

Some ducts suffer from non-reciprocity, as well, which means you may hear someone but be unable to get them to hear you. This is much more common on 160 meters than







on higher frequencies. If you suspect the DX to be the result of ducting, the best advice is to determine the proper azimuth to the DX contact and try to "shoot" your signals skyward using your antenna with the lowest take-off angles possible. (Given the size of most 160 meter antennas, you may not have much of a choice from which to choose!)

Tips for Improving Your Topband DX Operations

There are several important components that can improve your chances of successfully working DX on Topband.

The first, and probably the foremost, tip is to **wait for very quiet geomagnetic conditions.** The trick here is to wait for *sustained* intervals of quiet conditions *over the high latitude regions.* Using Boulder **k**-indices broadcast on WWV/WWVH at 18 minutes past each hour will not suffice, because Boulder, Colorado is far from the auroral ovals. The **k**-indices acquired at Arctic stations such as Inuvik, Baker Lake, and Cambridge Bay (all in Canada) are much more suitable for this application, because these stations are located within the auroral oval. Therefore, sustained three-hour **k**-indices of zero at these stations for periods of time lasting at least eight hours should prove to be a more accurate measure of the potential for 160 meter DX openings along high-latitude circuits. The reason for this is that research has shown that the auroral ovals require at least eight hours to contract to their most poleward positions (Ref. 7).

Sustained periods of zero **k**-indices are most common during the rising phase of the solar cycle, which we are now experiencing! They are the least common in the declining years of the solar cycle, when the appearance of low (solar) latitude and transequatorial coronal holes keep the Earth's geomagnetic field in a relatively continual state of flux. For the next two to four years, then, there should be a fairly large number of sustained quiet geomagnetic periods. Put another way, DX openings on Topband should be at their best during the next two to four years.

For reasons that are still uncertain, there often are periods of time immediately following the arrival of interplanetary disturbances when propagation on Topband is momentarily enhanced. This may be due to the fact that large changes can occur in the chemical makeup and neutral wind patterns of the ionosphere following the arrival of interplanetary disturbances from the Sun. It is entirely possible that changes in neutral winds might produce rarefied areas of D-region electron densities, resulting in abnormally low absorption levels for top-band signals. These conditions are, so far, mostly unpredictable, and they cannot easily be detected except through the observation of unusual DX on Topband or by means of specialized ionosondes. Greater research efforts into the nature and response of the neutral winds to interplanetary stimuli is required to solve this important problem.

Low and stable background x-ray flux values (in the 1 to 8 Ångstrom band) *may* help contribute to lower nighttime D-region electron densities and better Topband DX conditions.

Alternatively, although the D-region for the most part does dissipate after sunset, high x-ray flux values observed during the day can considerably increase electron densities in the day-side D-region. Speculative reasoning, then, suggests that residual effects on the night-side may become manifest (particularly during the first few hours after sunset) through the action of the neutral winds. In other words, during periods of high background x-ray flux values, propagation on Topband may be poorer for a slightly longer length of time after sunset—again, depending on the flow of the neutral winds at D-region altitudes.

The importance of electron gyrofrequencies cannot be understated. A successful Topband operator should keep in mind that signals will

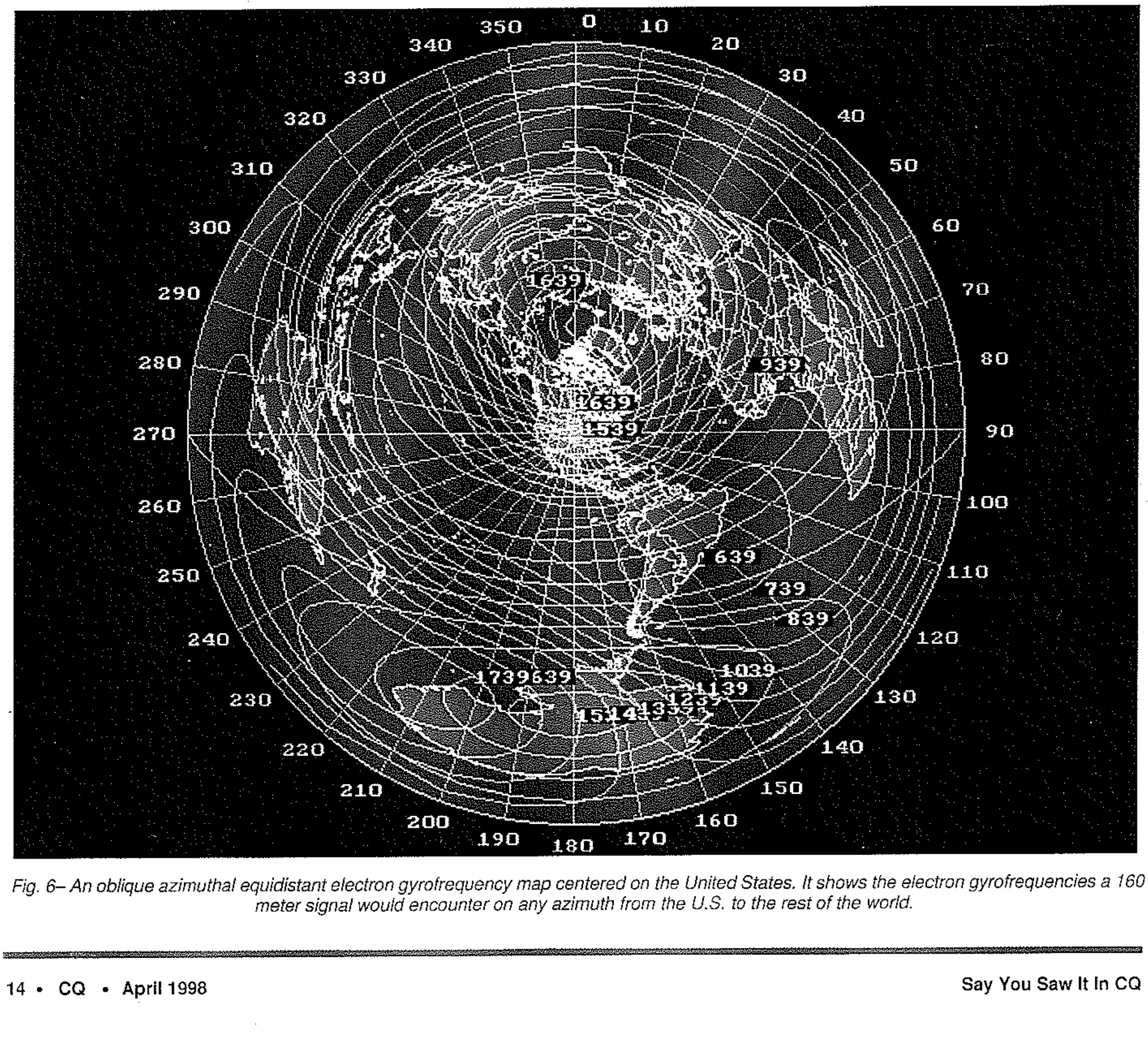


Fig. 6– An oblique azimuthal equidistant electron gyrofrequency map centered on the United States. It shows the electron gyrofrequencies a 160 meter signal would encounter on any azimuth from the U.S. to the rest of the world.

be less strongly absorbed and behave more like a conventional signal is expected to, *the farther away from the electron gyrofrequency is the carrier frequency.* To this end, it is wise to consult an electron gyrofrequency map when contemplating paths you want to use. Using paths that have steadily decreasing gyrofrequencies will have less of a degratory effect on signals than will paths that are associated with increasing gyrofrequencies.

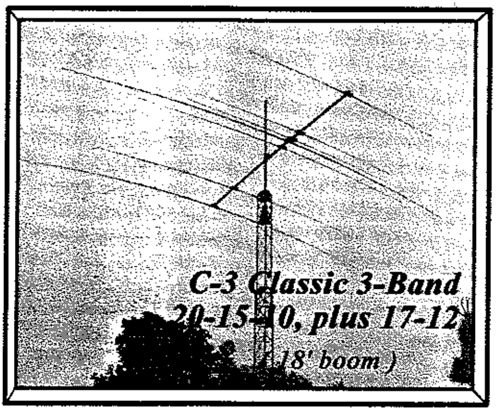
A very useful and unique map, centered on the United States and shown in fig. 6, can help individuals in the United States determine what the electron gyrofrequencies are for any signal azimuth. The radial azimuth "spokes" in fig. 6 are labeled on the outside of the image. The blue ovals are lines of geographic latitude (the red oval is the equator) and the whitish-green contours are the electron gyrofrequencies, given in *kHz* and spaced at intervals of 100 kHz. Fortunately for amateurs in the United States, the electron gyrofrequencies decrease on most signal paths except those which pass into Canada, the Arctic, and Siberia. Gyrofrequency conditions are best towards South America and Africa. Unfortunately for amateurs in the United States, electron gyrofrequencies are about as high as they can get, ranging from about 1300 to 1600 kHz. Propagation of topband signals within South America and even from South America to South Africa are much less affected by the gyrofrequency than are paths from North America to these regions because of the much lower electron gyrofrequency in South America and Africa.

Topband signals are very susceptible to sporadic-E. Even weak sporadic-E "clouds" that might not affect the higher frequencies noticeably can have a substantial impact on 160 meter signals by increasing absorption or refracting signals in wanted or unwanted ways. The only benefit that sporadic-E might provide for top-band operators is if signals reach the sporadic-E cloud from above (that is, on the way down from an F-layer reflection). In these instances, the signal will be reflected back to the F-region, which will effectively increase the distance traveled by the signal (in some cases, perhaps considerably). However, keep in mind that sporadic-E clouds are sometimes non-linear in shape and may contain bulges or other non-uniform structures that might scatter your signals instead of uniformly reflecting them along the great-circle path. Remember, too, that 160 meter signals are *easily* refracted, even by fairly low electron densities.

The ionosphere is a chemically active, electrically charged, fluid-like environment. Ripples in the electron density at the base of the ionosphere (and, indeed, at the bases of each of the layers in the ionosphere) exist and are continually traveling from place to place through the action of the neutral winds. This is important for propagation on lower frequencies because signals that encounter large traveling ripples in electron density can suffer from absorption fading, a periodic fading phenomenon that can produce moderately deep fading of Topband signals, as well as signal divergence (defocusing) and multipathing.

Computer Software Tools

Today there are substantial software tools available to the amateur and professional radio communicator that were not available a few years ago and that can be used to help moni-



tor Topband conditions. One of the more substantial ones for analyzing signal paths is the Proplab-Pro software package. Most of the maps and the ray-traced examples in this article were produced using this software. Another very substantial tool is a software package known as SWARM (Solar Warning And Real-time Monitor). This software can be used to monitor everything from geomagnetic and ionospheric conditions to solar activity and solar wind conditions, all in *real-time*. It is particularly valuable for the prediction of quiet geomagnetic intervals and the arrival of interplanetary disturbances.

In January 1998, the ACE (Advanced Composition Explorer) spacecraft began sending nearly continuous measurements of the solar wind from its vantage point outside of the Earth's magnetosphere (about a million kilometers "upstream" of the Earth, between the Earth and the Sun). This distance is fortuitous in that the spacecraft is able to detect the arrival of interplanetary disturbances up to an hour before they impact on the Earth. Because the data provided by the ACE spacecraft will be nearly continuously transmitted to the Earth, users of the SWARM software will be able to detect the arrival of these disturbances up to an hour before they actually reach the Earth's magnetosphere. This is sufficient time for radio communicators to prepare to take advantage of the momentary enhancements that can occur in Topband (and other band) conditions shortly after the arrival of these disturbances. The software will also audibly alert you when geomagnetic activity surpasses certain threshold levels. These audible alerts can be useful for radio communicators who may stop looking for DX opportunities on Topband if geomagnetic activity spawns **k**-indices of perhaps 4 or higher. The software will even fetch current solar flux values and sunspot numbers, solar imagery, auroral imagery from the POLAR spacecraft, up to 19 different types of daily, weekly, and monthly reports from forecast centers around the world, plot sunspot regions and other activity on a simulated image of the Sun, monitor x-rays for solar flares and protons that can devastate polar-path radio signals, and much more.

These software packages can be, to the serious radio communicator, as important as a good rig on a mountaintop. For additional information, contact the main Internet web pages for these software packages at <http://solar.uleth.ca/solar/www/swarm.html> and <http://solar.uleth.ca/solar/www/proplab.html>.

The Solar Terrestrial Dispatch

The Solar Terrestrial Dispatch (STD) is a superb source of information on the Sun and its effects on the space environment near the Earth. For readers who wish to investigate further the effect of the Sun on our ionosphere and on the propagation of their signals, whether on Topband or at frequencies higher in the radio frequency spectrum, the Solar Terrestrial Dispatch (STD) invites you to visit <http://solar.uleth.ca/solar> on the World Wide Web. This site provides current information on the state of the Sun and its effect on the Earth and on the space environment near the Earth. Current ionospheric maps of maximum usable frequencies, critical F2-layer frequencies, auroral activity sightings, solar activity observations, and much more is available at this site. The numerous services provided there are made possible through the kind cooperation of the University of Lethbridge, Canada.

Coordinated Amateur Radio Observation System (CAROS)

The Solar Terrestrial Dispatch is currently studying 160 meter propagation in greater depth, with a hope of isolating some of the more influential factors that might lead to improved models of propagation. They are, therefore, soliciting the involvement of all individuals who communicate or regularly listen on 160 meters. Although the 1997–1998 season for Topband will soon be over, we would appreciate receiving as much input as possible regarding observed contacts and propagation conditions on Topband. Further, we would like to continue to receive reports throughout the northern hemisphere's summer and on into the 1998–1999 Topband season.

In support of this and other radio communicators on higher frequencies, we have developed CAROS, which can be accessed through the STD on the World Wide Web (see below). We hope that Topband operators, as well as those who work the higher frequencies, will contribute their observations to our CAROS system. All reports are archived. The contributed reports can then be analyzed in detail and studied in combination with ionospheric data. It is hoped that through a collection effort such as this, we will be able to pry loose some of the secrets of 160 meter propagation. But the success of this project is dependent upon the number of reliable reports that are received. Please submit any observations you make to the CAROS system at <http://solar.uleth.ca/solar/www/subcaros.html>. The latest observations submitted to CAROS can be seen at <http://solar.uleth.ca/solar/www/caros.html>.

Other Available Internet Services

You may like to know that the STD is now offering solar and geophysical (including ionospheric) reports, alerts, and warnings, etc., to the public, free of charge. Anyone can subscribe to this service by visiting <http://solar.uleth.ca/solar/www/sublists.html> on the Web.

The STD also has constructed a Web page devoted specifically to 160 meter propagation that contains parameters that are thought to be reasonable indicators of potentially favorable top-band DX conditions. Included on this page are near-real-time images of the auroral oval and current geomagnetic indices for key Arctic stations. Armed with this information, and knowing the great-circle path your top-band signal is taking, operators should be able to determine whether DX propagation on Topband to various locations around the world might be possible. Keep in mind that this page is still experimental and that its developers do not yet claim to provide reliable propagation predictions for 160 meter signals. However, the Web page represents a good start that will serve as a base upon which to build theories and models. It will provide amateurs with the information required to help us prove or disprove the reliability of the propagation models employed. The URL is: <http://solar.uleth.ca/solar/www/topband.html>.

The Solar Terrestrial Dispatch is also offering a course over the Internet that teaches individuals how to predict space weather and radio propagation conditions. It is the most comprehensive course that can be taken over the Internet, and it covers all of the topics that have been discussed in this article, including topics such as the prediction of coronal mass ejections from the Sun and ionospheric disturbances and processes that can affect radio propagation. A complete list of topics and materials can be found at <http://solar.uleth.ca/solar/www/course.html>.

Conclusions

Topband is one of the last frontiers for radio propagation enthusiasts. It involves regions of the Earth's environment that are very difficult to explore and are poorly understood. These factors have led to our failure to predict propagation conditions with any level of accuracy. They also account for our inability to explain some of the puzzling mixtures of conditions that make this one of the most interesting and volatile bands available to the amateur service.

Topband may be the lowest band in the amateur spectrum, but it has one of the most promising and exciting futures possible!

Reference

7. Nakai, H., Y. Kamide, D. A. Hardy, and M. S. Gussenhoven, "Time scales of expansion and contraction of the auroral oval," *Journal of Geophysical Research*, Vol. 91, No. A4, pages 4437–4450. ■