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THE EFFECT OF IONOSPHERIC VARIABILITY ON THE ACCURACY OF HIGH FREQUENCY POSITION LOCATION

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By
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US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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The attainable accuracies in high frequency (HF) radio wave position location over ranges of several hundred kilometers are beset with errors of tens of kilometers due to constraints in three major areas: ionospheric variability and irregularity; system size limitations for easily fieldable systems; and sufficient data acquisition, processing, and interpretation. Of principal concern here is the area of ionospheric variability and irregularity.

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The temporal and spatial coherence of ionospheric structure has been considered with respect to its effect on the accuracy of HF position location. The findings show that medium and small-scale ionospheric structures most likely to affect HF position location accuracies have a spatial coherence on the order of 50 km and a temporal coherence on the order of 5 minutes. On this basis it is recommended that a multiple ionosonde net be used instead of a single ionosonde, such that an ionospheric sounding point is no more than 50 km from a potential radio wave reflection point, and that soundings be taken on the order of every 5 minutes or less.

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INTRODUCTION

High frequency (HF) radio wave propagation has long been the backbone of many short- and long-range communications networks. The reasons are straightforward: the technology is well established, the systems are relatively inexpensive and easily fieldable, and the reliability (while not perfect) is high enough to meet a large body of communication needs. Concomitantly, the interception of HF communications is one means of gaining additional intelligence. Taken an additional step, the interception of HF radio wave signals can also be used to locate the position of the transmitter, which knowledge may be of strategic and tactical value. The emphasis of this report is on the detection and location of HF radio sources over ranges of several hundreds of kilometers.

HF radio waves propagate in two modes: the ground wave, which propagates along the earth's surface, and the direct wave, which propagates through the atmosphere or free space. The ground wave can be detected out to distances on the order of 50 km, but the direct wave (which when reflected, or often refracted, from the ionosphere is known as the sky wave) can be detected out to very long distances. The radio source location techniques for a single-station locator entails measuring the angle of arrival of the signal of interest and determining the height of the ionospheric reflection point. The problem then consists of tracing the signal's path back through the ionosphere to the source, the accurate solution of which depends on a knowledge of the state of the ionosphere.

Currently, attainable accuracies in HF position location obtained by using a single-station locator still carry inherent errors of tens of kilometers or worse. These errors arise in three main areas: ionospheric variability and irregularity, locator system size limitations, and problems associated with data acquisition, processing, and interpretation. Of these areas, the ionosphere is the single largest source of error and is the principal concern here.

It is now generally agreed that real-time information on the state of the ionosphere is required for the optimum performance of a single-station radio source location system. Most often this information is acquired through a vertically incident ionospheric sounding made at that station. This procedure does yield real-time information on the height and tilt of the reflecting ionospheric layer at a single point, but this point is not the reflection point of the intercepted signal. It thus becomes important to quantify the spatial and temporal behavior of ionospheric structure and to estimate the spatial and temporal ranges within which ionospheric sounding information gathered at one point can be extrapolated to another point with minimal loss of position location accuracy.

The application addressed here is nominally that of a single-station locator which is tasked to locate the position of HF radio sources at ranges of more than a hundred but less than a thousand kilometers. At these ranges the intercepted signal has usually undergone only one reflection from the ionosphere. The next sections then outline the general properties of pertinent ionospheric irregularities and estimate the spatial and temporal coherence of these irregularities. The final section addresses the usefulness of a single ionospheric sounding as opposed to multiple and spatially separated soundings.

IONOSPHERIC STRUCTURE MOST AFFECTING RADIO SOURCE LOCATION ACCURACIES

In principle, the location of an HF transmitter can be found by simply measuring the azimuthal and elevation angles of the incoming signal and determining the height of the ionospheric reflecting layer. In practice, several features of ionospheric structure distort the otherwise straightforward picture of a uniform, concentric, smoothly reflecting (and refracting) ionosphere. Three phenomena shall be singled out because of their effects on radio source location: multiple reflective layers (particularly sporadic E), ionospheric tilts, and traveling ionospheric disturbances (TID). Of these, TID are the most important.

The ionosphere is divided into several regions, some of which contain reflective layers. The D region is located below 90 km in altitude and serves mainly to absorb radio waves below frequencies of 1 to 2 MHz. At night the electron density in the D region decreases so that absorption of waves in the middle frequency band (0.3 to 3 MHz) is no longer a problem.[1] Solar flares can produce enhanced (daytime) D region absorption of the lower portion of HF band (often up to 6 to 8 MHz), and at high latitude particle precipitation, again often associated with solar disturbances, can cause absorption in the lower HF band both night and day. Such outages generally last minutes to hours, although some high latitude outages (polar cap absorption events) have lasted days.[1] The E region, nominally between 90 and 150 km, is the first truly reflecting layer for HF radio waves. Daytime electron densities in the E region are normally only high enough to produce reflection for signals below 2 to 5 MHz (vertical incidence). At night the E region electron densities are low enough that HF frequencies are not reflected. Solar flares can produce much higher (daytime) E region densities and hence reflection of HF signals of up to 8 to 10 MHz.[1] Sporadic E is a special disturbance within the E region and will be discussed in greater detail below. The F region often produces two reflective layers, the F_1 layer generally between 160 to 200 km and the F_2 layer more in the altitude range near 300 km. The F_1 region, like the D and E regions, is under solar control--absent at night and often not present during the day in winter months; it is enhanced during solar flares. The F_1 and F_2 regions, or simply the F region, are responsible for most of the HF radio wave reflection or, for oblique paths, refraction. The F region shows a day-night variation, although the upper (F_2) portion is also controlled by plasma motions which produce more complicated behavior, and has enhanced electron densities during disturbed solar conditions, including the general solar sunspot cycle peak.[1]

The E and F regions are thus capable of producing different reflection heights for various HF frequencies depending on time of day and degree of solar activity. However, these problems are not the major ones in radio source location

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[1]H. Rishbeth and O. K. Garriot, 1969, Introduction to Ionospheric Physics, Academic Press, NY

because: (1) they occur periodically, usually daily, and can thus be anticipated and planned for, and (2) they are relatively homogeneous in spatial extent such that a single ionospheric sounding is representative of a very large area (hundreds to thousands of kilometers). Several charts, manuals, and prediction schemes which incorporate this general type of information on ionospheric behavior are available for HF frequency management. Table 1 gives a very brief synopsis of the points covered above.

In a generic sense, ionospheric tilts can refer to any deviation from the horizontal plane of the contours of constant electron density whether caused by large-scale phenomena such as solar ionization or by more transient, localized disturbances which will be discussed later. The effects of the tilts are errors in the estimation of the angle of arrival, principally in the elevation angle, and the misjudgment of the virtual height of the reflection point. For this report, ionospheric tilt shall refer to a tilt caused by the diurnally varying solar ionization rate in the F region. The effect is most noticeable at sunrise and sunset, and can thus be anticipated and accounted for.

The initial anomalous or irregular feature of the ionosphere is that of sporadic E. Sporadic E is a relatively thin layer of enhanced electron (and mainly positive metallic ion) concentration found most often between 100 and 110 km, although some layers are occasionally found as low as 92 km and higher than 120 km. Apparently, the concentration of ionization is due to wind shears in the neutral atmosphere which in turn may be a result of the propagation of acoustic-gravity waves through the E region.[2] Thus, sporadic E may be an E region manifestation of one type of traveling wave which also produces F region irregularities. (This phenomenon is true of the midlatitude sporadic E. Sporadic E-like occurrences are also found at low and high latitudes and are associated with the equatorial and polar electrojets. These occurrences are not considered further in this report.)[3] The properties of midlatitude sporadic E are summarized in table 2, based on Smith[4] [5] and Peterson.[6]

The patchiness of sporadic E is somewhat a function of the radio frequency employed. Higher density patches of a few tens to hundreds of kilometers, as

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[2]T. M. Georges, 1967, Ionospheric Effects of Atmospheric Waves, ESSA-TR-IER57-ISTA-54, US Government Printing Office, Washington, DC

[3]B. J. Fejer and M. C. Kelley, 1980, "Ionospheric Irregularities," Rev Geophys Space Phys, 18:401-454

[4]E. K. Smith Jr., 1957, World Wide Occurrence of Sporadic E, US Department of Commerce, National Bureau of Standards, Circular 582

[5]E. K. Smith Jr., 1962, The Occurrence of Sporadic E, Chapter 1 in Ionospheric Sporadic E, E. K. Smith and S. Matsushita editors, The Macmillan Company, New York

[6]V. L. Peterson, 1980, Ionospheric Irregularities, TR-80-005, Centennial Sciences, Inc., Colorado Springs, CO

TABLE 1. RADIO WAVE REFLECTION PROPERTIES FOR THE UNDISTURBED IONOSPHERE

	D Region	E Region	F_1 Region	F_2 Region
Altitude (km)	60-90	90-150	150-200	>200
Electron density range (cm^{-3})				
day	$\sim 10^3 - 10^4$	$5 \times 10^4 - 3 \times 10^5$	$10^5 - 10^6$	$5 \times 10^5 - 5 \times 10^6$
night	$<10^2 - 10^3$	$<5 \times 10^3$	$\lesssim 10^4$	$\lesssim 5 \times 10^5$
Frequencies reflected (upper limit*; MHz)				
day	no reflection, absorption below 1-2 MHz	2-5 MHz	3-9 MHz	6-20 MHz
night	no reflection no absorption	effectively no reflection	$\lesssim 1$ MHz	<6 MHz
Ionospheric tilts	not applicable	generally not applicable	Tilts of 1°-2° sometimes present during day; more often present during sunrise and sunset, with larger values occurring for 1/2 hour or more.	

*For vertically incident soundings

TABLE 2. PROPERTIES OF MIDLATITUDE SPORADIC E*

Structure	Patches of enhanced electron (and ion) density commonly a few hundred kilometers in horizontal extent. Smaller patches of higher density often embedded in larger, lower density patches. Vertical thickness generally 1-2 km at an altitude of 100-110 km.
Origin	Wind shears, probably from propagating acoustic-gravity waves.
Motion	Patches (not plasma) generally 50-100 m/s in all directions, a slight westward drift may be favored.
Duration	Several minutes to several hours.
Occurrence	More often in summer than winter; more frequent during day, with peak occurrence before noon and in some locations a secondary peak near sunset likely in summer. More frequent in lower portions of midlatitudes and most frequent off the east coast of Asia and Indonesia. Frequent of occurrence (i.e., detection) decreases as one moves to higher frequencies.

*based on Peterson[6]

discerned by radio frequencies above 5 MHz, may be found embedded in larger, lower density patches.[6] Both sizes of patches apparently move with similar velocities, which suggests a similar originating mechanism.

Because of the thinness of the layers, the relatively uniform horizontal layer smoothness, and the sharpness of the vertical gradients, sporadic E is often an aid in communications, providing a better reflecting surface than the F region. The principal deleterious effect of sporadic E for radio source location is the creation of multimode interference. Signals from the HF source may suffer reflections from both sporadic E and F layers, thus causing problems with the correct resolution of modes.

Traveling ionospheric disturbances have been noticed since the earliest days of radio wave propagation and were first studied extensively by Munro.[7 8] TID are essentially an ionospheric manifestation of an entire spectrum (not necessarily continuous) of waves propagating through the atmosphere. The spectrum of TID can be placed in at least two distinct categories: large-scale and medium-scale. According to acoustic-gravity wave theory, large-scale TID are associated with a discrete spectrum of guided waves whose modes are excited only by upper atmospheric sources and whose horizontal speeds are substantially greater than the (lower atmospheric) speed of sound.[2] Medium scale TID are associated with a spectrum of freely propagating internal waves which can be excited by sources at any altitude and whose horizontal speeds are less than the speed of sound. As one might suspect, medium-scale TID are much more common. (For more information on waves in the atmosphere see Georges,[2] Yeh and Liu,[9] Hines et al,[10] and the references therein.) A third category of smaller-scale TID is most likely the extension to higher frequencies and smaller size of the medium-scale TID. The spatial size is generally below the Fresnel-zone size of ionospheric sounders, and thus smaller-scale TID have not been as well documented. Table 3 summarizes the properties of these different categories.[2 11]

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[6] V. L. Peterson, 1980, Ionospheric Irregularities, TR-80-005, Centennial Sciences, Inc., Colorado Springs, CO

[7] G. H. Munro, 1950, "Traveling Disturbances in the Ionosphere," Proc Roy Soc (London), 202:208-223

[8] G. H. Munro, 1958, "Traveling Disturbances in the F Region," Australian J Phys, 11:91:112

[2] T. M. Georges, 1967, Ionospheric Effects of Atmospheric Waves, ESSA-TR-IER57-ISTA-54, US Government Printing Office, Washington, DC

[9] K. C. Yeh and C. H. Liu, 1974, "Acoustic-Gravity Waves in the Upper Atmosphere," Rev Geophys Space Phys, 12:193-216

[10] C. O. Hines and Colleagues, 1974, The Upper Atmosphere in Motion, Geophysics Mono Series 18, American Geophysical Union, Washington, DC

[11] N. N. Rao, 1981, Ionospheric Irregularities in HF Radio Source Location, Technical Report, D. O. 1684, TCN-80-304, Battelle Columbus Laboratories, Research Triangle Park, NC

TABLE 5. TRAVELING IONOSPHERIC DISTURBANCE*

Type of Disturbance	Wavelength and Structure	Motion	Period	Frequency of Occurrence	Source
Large scale	>1000 km horizontal wavelength	>300 m/s north to south	30 min - 3 h; usually 1-3 cycles	Infrequent, less than daily	Events in the auroral zone
	Wave front width on order of 1000 km				Strong correlation with magnetic activity
	Phase fronts titled nearly horizontal				
	Retains shapes over thousands of kilometers				
Medium scale	Tens to hundreds kilometers horizontal wavelength	100-250 m/s variable directions, with seasonal trends	10-100 min; several cycles or as trains	Daily, more common in daytime	Tropospheric phenomena
	Wave front width hundreds to over 1000 km				Upper atmospheric and polar winter sources
	Phase fronts titled 30°-60° from vertical				
	Do not retain shapes well over distances >100 km; energy does propagate globally				
Smaller scale	<10 km horizontal wavelength	100-250 m/s (est); variable directions	<10 min; long trains to families as wavelength decreases	Daily	Probably tropospheric; not well established
	Structure not well resolved				

*based on Smith[4,5] and Peterson[6]

Again, the main effects of TID are to cause errors in the angle of arrival, measured as the azimuthal and elevation angles, and the virtual height of reflection. Table 4 gives the magnitude of the errors in position location which the ionosphere can cause for selected ranges. A quick "rule of thumb" seems to be 10 to 20 km or 10 percent of range, whichever is worse.

SPATIAL AND TEMPORAL COHERENCE OF IONOSPHERIC IRREGULARITIES

The basic question which needs to be answered can be stated as follows: "If the structure of the ionosphere can be determined at one point, over what spatial ranges can that information be transferred, and for what time period is it valid?" For the simple case of a single vertically incident ionosonde, the pertinent information would be the height of the reflecting layer and the tilt of the ionosphere. The problems encountered are shown in figures 1 and 2.

Figure 1 is a plot of the incident angle (plotted as radial distance from the origin) versus the azimuthal angle of arrival (plotted as polar angle) for the return signal of a vertically incident ionosonde. The numbers represent one sounding each minute from 11:49 to 12:39 local standard time.[11 12] The general NW-SE pattern of a propagating wave is apparent, but so are the patterns of other smaller and differently oriented waves. This pattern is often typical for medium-scale TID which are superpositions of several frequency components. Figure 2 shows the constant plasma frequency contours (that is, variation of reflection heights) as a function of time for the passage of a large-scale TID. This large-scale wave can cause ionospheric tilts of up to 3° to 4° for short periods of time, with tilts on the order of 1° being common for an hour or more.[13]

The relevance of ionospheric data taken at one point when extrapolated out to successively larger distances may be estimated from the following example. The positions of known transmitters are estimated from received signals, and the fixing errors between calculated and known ranges are determined in two ways: first, by assuming the ionosphere is uniformly flat, and second by assuming the ionosphere is tilted, based on the ionosonde data at the receiver. The scatter plots of the fixing errors for three transmitters at successively greater distances are shown in figure 3.[11] The 45° line in each

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[11]N. N. Rao, 1981, Ionospheric Irregularities in HF Radio Source Location, Technical Report, D. O. 1684, TCN-80-304, Battelle Columbus Laboratories, Research Triangle Park, NC

[12]E. W. Ernst, J. D. Dyson, and N. N. Rao, 1974, HF-DF Techniques Investigation, Final Report, Volume I, ECOM-0125-F, US Army Electronic Warfare Laboratory, Fort Monmouth, NJ

[13]N. N. Rao, 1975, "A Large Scale Traveling Disturbance of Polar Origin," Planetary Space Sci, 23:381-384

TABLE 4. MAGNITUDE OF ERRORS IN POSITION LOCATION ACCURACY DUE TO ERRORS IN ANGLE OF ARRIVAL FOR E AND F REGION LAYERS

Range (Actual)	200 km		300 km	
Height of Reflecting Layer	105 km	250 km	105 km	250 km
Range Error (km) for:				
1° elevation angle uncertainty	6.9	9.8	10.9	11.5
3° elevation angle uncertainty	20.6	29.3	32.7	34.4
Cross-Range Error (km) for:				
1° azimuthal angle uncertainty	3.5	3.5	5.2	5.2
3° azimuthal angle uncertainty	10.5	10.5	15.6	15.6
Range Error (km) for:				
10 km height uncertainty	19.4	7.7	27.6	11.5

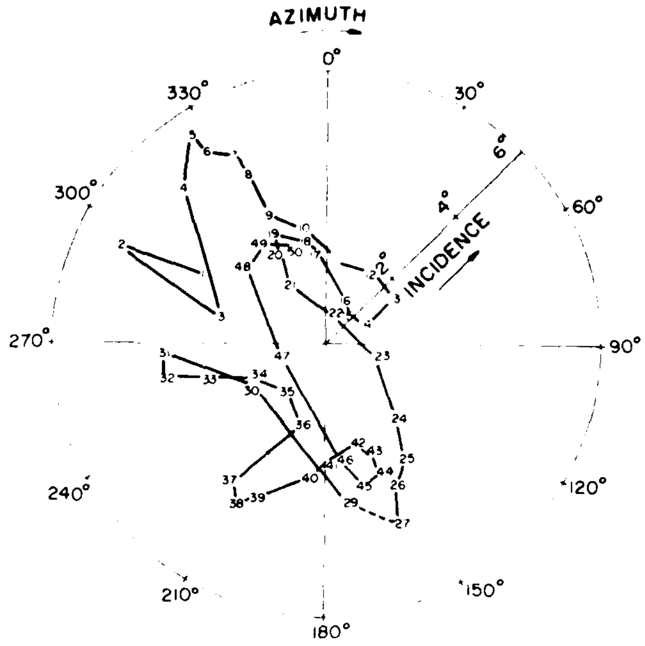

Figure 1. Incident angle, plotted as radial distance from the origin, versus azimuthal angle, plotted as the polar angle, for the return signal of a vertically incident ionosonde over a 50-minute interval (based on Ernest et al[12]).

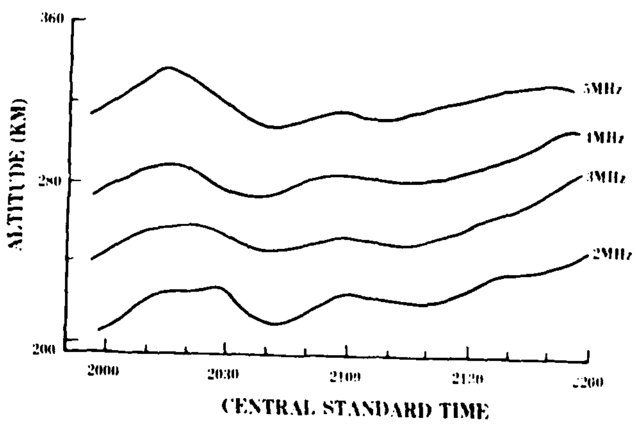

Figure 2. The altitude of the constant plasma frequency contour (i.e., signal reflection heights) versus time for a large-scale TID (based on Rao[11]).

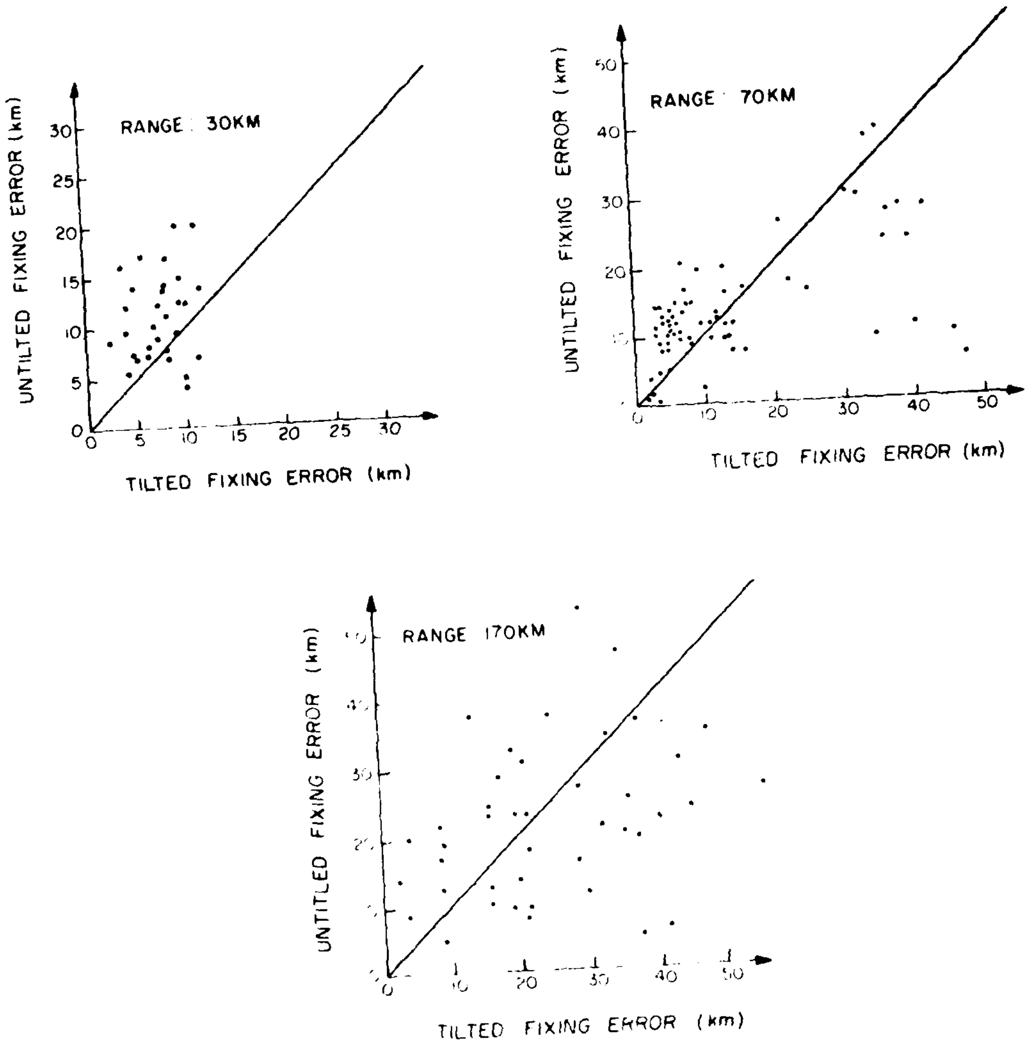

Figure 3. The scatter plots of the radio source location errors using two ionospheric models for three transmitters at successively greater distances (based on Rao[11]).

plot corresponds to the condition of equal errors from the two models. Thus points above the line correspond to smaller "tilted ionosphere" fixing errors, while points below the 45° line correspond to smaller "untilted" fixing errors. For the case where the actual range is 30 km, use of the tilted ionosphere model (that is, "extrapolating" the ionosonde data out to a point 15 km away) produces noticeably smaller fixing errors. The same is true when the range is extended to 70 km (that is, ionosonde data are extrapolated to a point 35 km away), although to a somewhat lesser extent. However, when the range is extended to 170 km (ionosonde data must be extrapolated 85 km), there is no advantage to using the tilted ionosphere model over the untilted one. Thus, in this example, extending ionospheric data from one point to another for distances of more than 50 to 100 km does not seem to be of any advantage.

Similar conclusions have been reached by measuring the angles of arrival of HF signals from a series of geographically spaced transmitters. Assuming a one-hop propagation path, some useful results were obtained by cross-correlating the angle of arrival deviations of the signals from pairs of transmitters.[11 14 15] A maximum in the cross-correlation function means that the variations in the angle of arrival at one location are reproduced at the second location some time, T, later. The results indicate significant decorrelation of a persistent ionospheric pattern over distances of 50 to 100 km. This decorrelation does not mean that a single frequency component of the composite disturbance necessarily decorrelates over distances on the order of 100 km, but rather that interference between waves from different sources, or from the same source traveling different paths, can result in the observed decorrelation.

The approximate ranges of the quasi-periodic variations of several ionospheric irregularities have been listed in table 3. While there have been numerous studies pertaining to the statistics of occurrence of characteristic periods or frequencies, the subject of temporal coherence seems to have received less attention. The temporal coherence of the ionospheric waves (particularly the medium-scale TID) observed at a given location depends on the sources of the waves and the duration of the sources. In practice, many waves due to several sources or multipath propagation from a single source are probably present at any given instant of time. One can assign a decorrelation time to a group of waves which would essentially represent the time it takes the group to change form due to interference of the several components. This approach was taken

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[11]N. N. Rao, 1981, Ionospheric Irregularities in HF Radio Source Location, Technical Report, D. O. 1684, TCN-80-304, Battelle Columbus Laboratories, Research Triangle Park, NC

[14]E. W. Ernst, J. D. Dyson, and N. N. Rao, 1975, HF-DF Techniques Investigation, 2nd Quarterly Report, RRL Report 456, Radio Research Laboratory, University of Illinois, Urbana, IL

[15]K. E. Hoover, 1976, "Ionospheric Modeling for HF Radio Source Location from a Single Site," Ph.D. Thesis, University of Illinois, Urbana, IL

by Walton[16] who found a predominant decorrelation time of approximately 5 minutes. The approximate range in speeds for medium-scale TID is 100 to 250 m/s. Using the decorrelation time of 5 minutes, this factor would yield a "decorrelation distance" in the range of 30 to 75 km, in good agreement with the previous estimates of spatial coherence.

Therefore, the spatial and temporal coherences of ionospheric sounding information appear to be on the order of 50 to 100 km and 5 minutes, unless sophisticated techniques of spectral analysis are employed to extract those individual waves which remain coherent over much longer distances and whose sources remain active and periodic for longer time periods.

DISCUSSION

The previous sections have outlined the types of ionospheric phenomena which are most likely to affect radio source location. The magnitude of some of the induced errors in position location accuracies and the spatial and temporal coherence of medium-scale TID have been estimated.

Most of the ionospheric irregularities considered here can be thought of as wave-like phenomena which propagate through the neutral atmosphere, with corresponding effects on the ionized component of the atmosphere. The possible exception, at least in behavior, is sporadic E, although the wind shears responsible for sporadic E may be due to gravity waves. The main effect of sporadic E is to introduce uncertainty as to which ionospheric layer, E region or F region, the signal is returning from and to provide additional opportunities for multimode reflection of signals. The concepts of spatial and temporal coherence, or decorrelation, are applicable to sporadic E only in the sense that the physical size and motion of the patch will give some estimate of how long the phenomenon is expected to persist at any one given point.

Ionospheric tilts and traveling ionospheric disturbances produce the major problems in radio source location by introducing error in the angle of arrival and uncertainties in the height of the reflecting layer. Multiple reflections from wave-like or corrugated layers also produce multimode interference. The ionosphere tilts due to solar influence; and the large-scale TID show good spatial and temporal coherence, maintaining their shapes over long distances and for times on the order of an hour or more. Superimposed on these more regular waves are the spectra of medium-scale and smaller-scale TID which are the most frequently occurring ionospheric irregularities and the ones showing the least spatial and temporal coherence. While single frequency components of medium-scale TID may persist for longer distances and periods of time, the composite TID seems to decorrelate over distances of 50 to 100 km and times of 5 minutes. Table 5 provides a summary of this group of properties of the various ionospheric structures.

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[16] Walton, E. K., 1971, "An Investigation of Directional Deviations of Steeply Downcoming HF Radio Waves Due to Traveling Ionospheric Disturbances," Ph.D. Thesis, University of Illinois, Urbana, IL

TABLE 5. DECORRELATION PROPERTIES OF IONOSPHERIC STRUCTURE

Type	Spatial Decorrelation	Temporal Decorrelation	Major Effects
Multiple layers (E, F_1, F_2)	Thousands of kilometers	Hour or longer	Uncertainty in height of reflecting layer Multimode propagation
Ionospheric tilt (solar effect)	Hundreds to thousands of kilometers	30 minutes or longer	Uncertainty in angle of arrival and height of reflecting layer
Sporadic E	~hundreds of kilometers depending on the size of the patch	Minutes to hours, depending on relative location of patch and its drift velocity	Uncertainty in height of reflecting layer Multimode propagation
Large-scale TID	Thousands of kilometers	30 minutes to several hours	Uncertainty in angle of arrival and height of reflecting layer Multimode propagation
Medium-scale TID	50 to 100 kilometers	~5 minutes	Uncertainty in angle of arrival and height of reflecting layer Multimode propagation

The emphasis of this report has been implicitly directed toward the concept of a single-station locator using a single, vertically incident ionospheric sounder. One basic constraint in radio source location is that the reflection point of the intercepted HF signal is some distance from the receiving site. For a spatially and temporally uniform, or at least slowly varying, ionosphere this constraint would present no problem. In reality, however, ionospheric irregularities reduce the usefulness of information gathered at one point when transferred to another point. Medium-scale TID seem to place the severest limitations on extrapolation of state of the ionosphere information. The basic space and time decorrelation parameters have been listed above.

If the concept of the single-station locator is retained, then the inherent problem of errors due to the ionospheric propagation path may be approached by either living within the constraints of the single point sounding or expanding the ionosonde network. Four options will be explored: (1) limit the use of the system to live within the current constraint of a single, overhead sounding; (2) place the ionosonde at the anticipated midpoint of the propagation path; (3) resolve the various frequency components of the ionospheric disturbance; and (4) employ an integrated network of ionosondes.

The first option recognizes the basic constraints of the available ionospheric data and limits the use of a single-station locator to within these constraints. This option implies that the system would be of essentially strategic use but would have the advantage of being essentially self-contained and capable of being fielded well behind the forward battle area. The inherent position location errors would be on the order of 10 percent of range.

The second option attempts to gather ionospheric data where it would be most useful, near the anticipated ionospheric reflection point. This option implies a preselection of range and direction over which radio source location will be attempted so that the system and the sounder can be optimally positioned. Thus additional constraints on system use have been imposed, not the least of which is the transfer of data from the ionosonde to the receiving station. Once the step of moving the ionosonde has been taken, it is a natural extension to consider using several ionosondes.

A basically analytic approach to the problem of decorrelation of ionospheric data would be to resolve the various frequency components of the medium-scale TID. The individual components apparently maintain their coherence and propagate over distances and times longer than 50 to 100 km and 5 minutes. While this approach is conceptually straightforward, it is not clear how much ionospheric data would be needed as input. It would appear, however, that data from several ionosondes would be needed. The additional data correlation and analysis effort would place very large requirements on any fielded computer system.

The fourth option employs an integrated network of ionosondes. (The potentially large data requirements for the analytic approach of the third option implicitly implied such a network also.) An integrated network of ionosondes could be used to gather sufficient ionospheric data to quantify the real-time structure of the ionosphere over a large area. The emphasis here is to simply specify the structure with sufficiently useful detail and not to attempt a complicated analysis of ionospheric wave patterns. As an illustration, one ionosonde is placed at each corner of a square 200 km on a side as shown in figure 4. By using vertical soundings at each ionosonde and oblique soundings between each ionosonde, the researcher could determine the structure of the ionosphere (nominally reflection heights and tilts) at nine points along the perimeter and at the center of this square. Thus 78.5 percent of all the points within a slightly larger superimposed square, 300 km on a side, would be within 50 km of a sounding point and therefore within the "decorrelation distance." No point in the square would be more than 71 km from a sounding point. In this manner a relatively large area can be covered by as few as four ionosondes, provided they are integrated into a network by using both vertical and oblique soundings.

A single-station locator could be located either within the ionosonde net or to the rear of the network. A leading edge of the network could itself be positioned near the battle area. Thus radio source location could take place from the battle area itself and then to the rear of the battle area on the opposite side commensurate with the single-station locator's setback position on our side. The constraints on a system of this type are that the ionosphere should be sounded approximately every 5 minutes and that the complexity of data transfer and data handling has been greatly increased. However, the advances in computer techniques are now reducing the severity of this latter problem. The advantages are that the potential is now there to develop an HF radio source location system which is able to reduce position location errors to a few percent of range, rather than the current 10 percent.

CONCLUSION

In summary, the effects of ionospheric irregularities on radio source locations have been investigated. The findings showed that ionospheric data (tilt and virtual height of reflection) taken at one point lose their validity when extrapolated over distances of 50 to 100 km or times of more than 5 minutes. Thus ionospheric soundings should be made more frequently than 5-minute intervals. A single ionosonde is usually not sufficient to adequately represent a large enough area of the ionosphere. An integrated network of ionosondes, using both vertical and oblique soundings, is recommended.

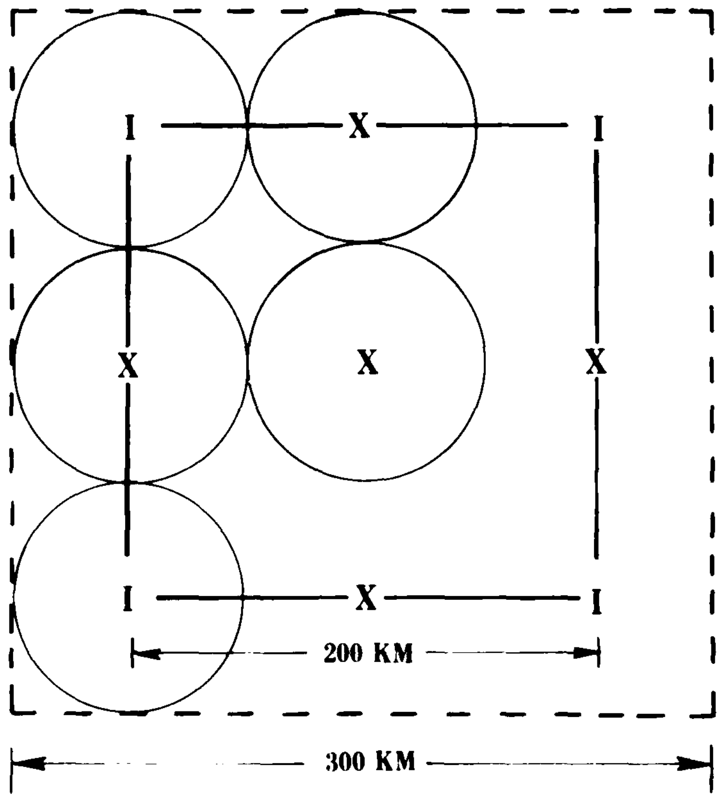

Figure 4. Schematic of how to locate four ionosondes such that maximum ionospheric data over a large area can be gathered from both vertical and oblique sounding. I indicates the location of an ionosonde and a vertical sounding point; X indicates an oblique sounding point. The circles indicate a "decorrelation" radius of 50 km

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