OBLIQUE IONOGRAMS AND HF PROPAGATION ASSESSMENT

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ABSTRACT

The capability for efficient management of HF frequency resources arises from a system which can accurately forecast the HF propagation characteristics of a set of communication links. It is discussed how such a system can be based on strategic deployment of HF sounders, coupled with a particular data analysis plan. Results are demonstrated with respect to the processing of data from a particular oblique-incidence sounder network.

INTRODUCTION

The selection of frequency for an HF communication link is often initially based on predictions of a statistical model, such as MINIMUF [Rose et al, 1978a, 1978b, 1979]. Deviations of the ionosphere from a statistical average state, however, can invalidate these predictions, and it is therefore desirable to include sounder measurements of actual ionospheric conditions. For example, some improvement is obtained [Uffelman, 1981; Uffelman et al, 1984a, 1984b] by periodically adjusting the sunspot parameter of MINIMUF to fit the measurements of MUF on an oblique sounder path. This procedure can be adapted quite easily to existing systems.

A future generation of improvement for HF propagation forecasting systems may be sought in the strategic deployment of HF sounders and in data analysis innovations. The procedure would be to first determine dynamic trends in ionospheric profiles at selected points, next extrapolate in time and interpolate in space to forecast ionospheric profile characteristics along any communication link of interest, and finally compute the oblique ionogram for this communication link, which is thus essentially completely characterized. Computer-generated displays for all communication links of interest would enable efficient management of HF frequency resources. Some specifics of the analysis procedure are discussed next.

DATA ANALYSIS

A network of oblique sounders was deployed in the western United States in Dec., 1982 for a particular project [Daehler, 1983]. The network of TRQ-35 sounders consisted of six transmitters T1, T2, -- T6 and one receiver R, shown in Figure 1. Also shown is the midpath point for each sounder, denoted by an X-mark and the transmitter number. For most of 17 days, HF oblique ionograms were collected from

these sounders at 15 minute intervals. The processing of these ionograms is in its early stages. Hence, the results presented here are of a preliminary nature.

The processing consists of converting these oblique ionograms to ionospheric true height profiles, i.e., plots of altitude vs. the square of plasma frequency (proportional to electron density), by making use of a recently reported technique [Keilly, 1984]. The oblique ionograms display only the relative times of transit (or time delay) of a pulse on different raypaths between the transmitter and receiver vs the wave frequency f . Our procedure is to: (1) estimate the relative time delay for the E-layer trace at $f=0$, (2) assume that the bottom of the E layer is at 90 km, and thus obtain a correction for obtaining absolute time delays from the observed relative time delays, (3) calculate the ionospheric true height profile solution from the bottom of the one-hop trace upward, as a kind of light pen device is advanced in discrete steps along the trace, and (4) extrapolate a best parabolic fit of the last five solution points up to the F layer maximum. The profile computed is thought to characterize the midpath ionosphere (cf. x - marks in Figure 1), since most of the ray-bending occurs in this region, and there is some experimental support for this [Basler and Scott, 1967]. The calculated true height profile is then characterized by a set of nine parameters associated with the idealized profile shown in Figure 2. The idealized true height profile is characterized by a series of segments with a dependence of $R^2 f_N^2$ on the radius R (altitude + radius of earth) which is either linear or parabolic. The dependence is parabolic up to the E layer maximum at (foE^2, h_mE) , linear in the E-F transition region up to (fbF^2, hbF) , linear in the lower F region up to $(foF1^2, hmF1)$, and parabolic up to the F layer maximum at $(foF2^2, hmF2)$. The ninth parameter is $Y2$, which is the semithickness of the best-fit parabola for the last five solution points. The last three parameters are determined from the best-fit parabola. The other parameters are visually estimated, so that one obtains a reasonably good fit of the idealized profile to the calculated true height profile. For example, the value of $foF1^2$ is taken at that point where the parabolic fit begins to deviate significantly from the calculated profile. The analytic form of the idealized profile is

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convenient for calculations based on it, as discussed later.

The preceding method was carried out on sounder data for December 6, 1982 in the morning, between about 1600 and 1800 hours (UT). The data from sounders 4 and 6 have not been processed yet, because of difficulties in seeing the E layer trace, but this problem is being corrected. The nine profile parameters have been displayed graphically with time, along with calculations of actual and effective solar zenith angle and foF2 from MINIMUF. In this time domain, 1600-1800, the cosines of the actual and solar zenith angles are monotonically increasing and not significantly different from each other. The three F2 parabolic parameters are displayed in Figures 3-5 as a function of the square root of the cosine of the effective solar zenith angle. This effective angle in MINIMUF incorporates a lagged response of the upper F region to the solar perturbation. The circled dots in Figures 3-5 are obtained from the true height profile calculations for sounders 1,2,3, and 5. Straight-line segments connect these points. The dashed lines in these figures give the predicted behavior from MINIMUF, where the underlying ionospheric model is that of a parabolic F layer with hmF2 = 290 km, Y2 = 81 km, and foF2² containing the statistical variation.

The straight-line MINIMUF prediction in Figure 3 is based on a 10.7 cm radio flux value 210.4 for Dec. 6, 1982. Note that the four different sounders give a consistent variation of foF2² with time and solar zenith angle, as might be expected from the proximity of the midpath points to each other in Figure 1. It is significant that the slope of this variation is markedly different from the MINIMUF prediction. The MINIMUF calculations of MUF are therefore also expected to have the wrong slope. The figures tend to illustrate the limitations of a statistical model, even one with a simple updating provision.

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Figures 3-5 indicate that, while the curves tend to have an average trend, there are often fairly large deviations from the trend from one point to the next for a given sounder. It is not yet clear how much of this is from local ionospheric variations, and how much arises from data-processing ambiguities, but it does suggest a further procedure. From the standpoint of predicting ionospheric parameters, it is important to use the average behavior in Figures 3-5. This can be done by a linear regression analysis on the variables in these figures, either for several sequential measurements for a given sounder, or for the results on a shorter time scale from a small number of sounders whose midpath points cluster over a fairly small region, as for those in Figures 3-5 (cf. Figure 1). Similar remarks apply to the rest of the nine parameters. It is hypothesized at this time that, since the upper F region formation dynamics is different from the Chapman layer theory description at

lower altitudes, the linear regression analysis will have the form

$$U_i = A_i + B_i (\cos X_{\text{eff}})^{1/2} \quad (i=1,2,\dots,5)$$

for the parameters foF2², foF1², hmF2, Y2, and hmF1 of the upper F region and the form

$$L_i = A_i + B_i (\cos X)^{1/2} \quad (i=6,7,\dots,9)$$

for the parameters fbF², foE², hbF, and hmE of the lower altitude regions, where the dependence is on the actual solar zenith angle. The data processed thus far suggest that the B_i coefficients will be relatively small for hbF and hmE, and that the A_i coefficient will be quite small for foE². Once the linear regressions coefficients A_i and B_i have been obtained, they can be used to predict the idealized profile in Figure 2 at later times. An oblique ionogram can be relatively easily calculated for profiles of this type, since all the integrals involved can be evaluated analytically. A computer program has been written for this purpose. Hence, the propagation characteristics can be predicted for any communication link with midpath nearby.

The next question is how the above analysis for a set of widely separated ionospheric points can be used to predict propagation characteristics on communication links with different midpath points. An attempt would be made to interpolate the known regression coefficients to get those for the midpath points of interest. Then the oblique ionograms could be computed, as before. Whether this interpolation would be done as a function of magnetic dip angle, or in some other way, remains to be seen. Some progress is expected from further analysis which includes the data from sounders 4 and 6 in Figure 1.

At this time the prospect of an efficient centralized HF frequency management system, based on measurements from a network of oblique-and vertical-incidence sounders and the above ideas for data analysis, seems realistic. Further developments will be reported.

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Fig. 1. Configuration of oblique-incidence
sounders in 1982 operations.

Fig. 2. Idealized true height profile with
nine-parameter designations.

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Fig. 3. foF2 plots, 1600-1800 UT,
Dec. 6, 1982.

Fig. 4. hmF2 plots, 1600-1800 UT,
Dec. 6, 1982.

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Fig. 5. Y2 plots, 1600-1800 UT,
Dec. 6, 1982.

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