REPORT 1012-1

OPERATIONAL MODELLING OF HF RADIO PROPAGATION CONDITIONS AT HIGH LATITUDES

(Question 27/6)

(1986-1990)

1. Introduction

HF communication at high latitudes is a difficult area of study and practical application. The current state of knowledge of the high latitude ionosphere allows long-term predictions for HF communications and approximate real-time specifications of the high latitude ionosphere. The ability to provide short-term forecasts of HF communications relies on the ability to project the observed morphology forward in time. The special properties of the high latitude ionosphere affecting radio communications have been summarized in Report 886. Other reviews of the high latitude ionosphere and predictions of its properties have been published in the Solar-Terrestrial Predictions Proceedings [Donnelly, 1979, 1980] (see, for example Besprozvannaya et al. [1979], Hunsucker [1979a, b] and Vondrak [1979]), in a special issue of Radio Science [Hunsucker and Greenwald, 1983], by Tsunoda [1988] and by Belrose [1988].

2. Models of the high latitude ionosphere

The ability to predict the propagation of HF radio waves at high latitudes requires a model of the spatial and temporal distribution of electron density in the high latitude ionosphere. Because of the very definite spatial structure in the auroral and polar cap regions of the high latitude ionosphere, the specific propagation predictions may be very sensitive to the positioning and dynamic changes of the structures.

Among the high latitude ionospheric features that should be modelled for HF predictions are the following [Hunsucker, 1979b]:

(a) location and extent of the auroral oval as a function of magnetic activity;

(b) E- and F-region parameters in the auroral oval, mid-latitude trough, day-time cusp, and polar cap;

(c) profile of N_e versus height between E and F2 regions (also important for prediction of ducted propagation);

(d) auroral absorption, polar cap absorption (D-region effects);

(e) E- and F-region irregularities that cause diffuse multipath, rapid flutter fading, and off-great-circle propagation;

and also [Buchau et al., 1985]:

(f) location and extent of "patches" and sun-aligned arcs, within the polar cap, which give rise to scintillation.

For HF propagation prediction purposes, the shape of the profile and the steep gradients of the high latitude ionosphere must be represented in three dimensions. Predictions of MUF/LUF using triangulation, mode-definition and location of reflection points, may be of limited usefulness because strong horizontal gradients cause large changes in mode geometry and absorption estimates.

The present HF propagation prediction capability at high latitudes is statistical, using averaged synoptic data that ignore small scale (< 100 km) structure and transient phenomena (< 3 h). Important features such as auroral arcs and substorms are completely neglected. Some models do contain auroral E, auroral Es, auroral absorption, and F1 and F2 regions. The models incorporated into HF propagation prediction computer programs have, for the most part, not been verified with oblique path measured data.

2.1 *Available models for predictions*

The availability of high latitude ionospheric models for HF prediction purposes has been reviewed by Hunsucker [1979b]. The characteristics and process of high latitude F-region large scale (>10 km) and small scale (<10 km) irregularities have been reviewed by Tsunoda [1987] and a descriptive model has been derived. Several models are available which include features (a) to (f) above. Data accumulated with ground-based and airborne ionosondes have been used to develop a model of the structure of the high latitude ionosphere [Elkins and Rush, 1973]. This model has been further modified using incoherent-scatter radar (ISR) data [Vondrak *et al.* 1977]. The new model retains the foF2 and hmF2 values in the earlier polar model [Elkins and Rush, 1973], and incorporates an auroral E layer (essentially equivalent to blanketing Es) and a valley in the electron density profile determined from ISR data, as well as an absorption model that varies with magnetic activity.

The USSR has developed statistical models of the structure of the high latitude ionosphere [Kovalevskaya and Zhulina, 1979; Avdiushin *et al.*, 1979]. Differences have been noted between USSR and US predictions in the case of auroral absorption and foF2 in the mid-latitude trough during solar maximum. During magnetic disturbances, the USSR has identified three distinct regions of auroral absorption whereas the absorption model given by Vondrak *et al.* [1977] displays two time/latitude regions of enhanced absorption. Models also differ in describing the gradients of foF2 in the trough region at solar maximum [Miller and Gibbs, 1975].

Foppiano and Bradley [1983] have developed a method of predicting auroral absorption intensities and this is used in the CCIR method of HF field strength estimates (see supplement to Report 252). The day-to-day statistical distribution of absorption is found to be log-normal, and the probability of a given level being exceeded can be specified if one knows two parameters, the median absorption, A_m, and the probability of 1 dB being exceeded, Q_1. Foppiano and Bradley [1984] examined statistical variations of absorption data measured with a riometer on different days at a given hour. A new approximate expression was established between A_m and Q_1, and the family of amplitude distribution curves consistent with this relationship were presented. Results using this relationship and those found in earlier investigations were compared. Foppiano and Bradley [1985] have also incorporated geographical, diurnal, seasonal and solar cycle variations. Hargreaves et al. [1985] suggest that changing solar cycle activity be accounted for in the model by use of magnetic activity index (such as Ap) rather than sunspot number in view of the fact that auroral precipitation depends on solar wind rather than on sunspots directly. A method for auroral absorption intensity prediction has been developed by Zhulina *et al.* [1983]. This too, is based on an empirical model for the probability distribution of auroral absorption intensity that has been derived from observations of cosmic radio noise absorption by riometers, which for this study were located in the Euro-Asian sector of the Northern Hemisphere. In this method the space-time variations of auroral absorption are represented in the form of maps and tables [CCIR, 1982-1986a, b]. An analytical approximation of these variations in auroral absorption is given in [CCIR, 1982-1986c].

A model including a coarse F-region $N(h)$ classification of the various structural regions (trough, oval, etc.) and rather qualitative information on D and E regions effects on HF propagation has been used [Rush *et al.*, 1982] to modify monthly median ionospheric models, for specification of HF propagation conditions, and for prediction purposes.

The use of theoretical models can further the understanding of the chain of events linking activity on the Sun to modifications of the high latitude ionosphere and its effects on HF communications. Overall schemes specifying and forecasting the solar wind, the magnetosphere, the thermosphere, the geomagnetic field, and the high latitude ionosphere have been developed [Akasofu, 1981, 1982, 1983; Hakamada and Akasofu, 1982; Fuller-Rowell et al., 1987]. Theoretical models [Watkins, 1978; Sojka *et al.*, 1982] of the high latitude ionosphere alone are able to reproduce successfully many of the observed features such as the "main trough", "ionization hole," the "tongue of ionization," the "aurorally produced ionization peaks," and the "UT effects".

The descriptive model of F-region irregularities derived by Tsunoda [1987] appears to unify most of the diverse and independent high latitude observations.

2.2 *Real-time specification*

To optimize system performance, HF communication systems and HF radars require real-time specification of the main auroral/polar ionospheric features such as arcs, the mid-latitude trough, and the polar cusp. High inclination polar orbit satellites can examine the polar and auroral regions in real-time at several optical wavelengths. Ray tracing in near real-time would allow the prediction of HF propagation characteristics such as mode availability, dispersion, multimode and non-great-circle propagation.

2.3 *Short-term forecasting*

To improve existing forecasting programmes, spacecraft measurements of solar wind parameters (such as velocity, density and the interplanetary magnetic field) could be used to predict auroral oval characteristics, total magnetospheric energy input, and current system morphology [Vondrak, 1979]. High altitude satellites providing real-time global pictures of the ionospheric response to the entry of particles from the magnetosphere, could greatly aid the forecasting of detailed changes in structure, size and location of enhanced electron density regions in the ionosphere. Additional data on the high latitude ionosphere (auroral oval, cusp and polar cap) in the range of approximately 69° to 81° invariant magnetic latitude are being obtained by incoherent scatter radar [Kelly, 1983]. Within the polar cap itself, a ground-based digital sounder is supplying continuous measurements of the bottomside F layer, [Buchau et al., 1987].

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* The abbreviation STPP refers to the Solar-Terrestrial Predictions Proceedings, published in four volumes by the National Oceanic and Atmospheric Administration, US Department of Commerce, and edited by R. F. Donnelly (see [Donnelly, 1979 and 1980]).

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