COMPARISON OF TWO APPROACHES OF ESTIMATING IONOSPHERIC SPACE WEATHER EFFECTS ON HF COMMUNICATION LINKS

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ABSTRACT

Ground backscatter from SuperDARN radar located at Hankasalmi, Finland, is used to estimate the ionospheric plasma frequencies and thereby MUF (maximum usable frequency) for a 1000 km communication link. These estimates are calculated for geomagnetically quiet days during 1996. On the other hand the ray-tracing program PropLab Pro is used to get MUF estimates based on IRI (International Reference Ionosphere) for these same days. During quiet conditions both methods give similar estimates, but during disturbed conditions results based on SuperDARN may deviate significantly from PropLab estimates. Therefore SuperDARN radars can be used to get better, near real-time MUF estimates.

INTRODUCTION

Space weather effects can strongly influence high frequency (HF) communication by changing ionospheric conditions between the transmitter and receiver sites. This is especially true at high latitudes and during high solar activity. As HF communication methods are widely used e.g. by military organizations, emergency systems and aviation control, it is important to make accurate measurements and forecasts of communication link parameters. For example, the maximum usable frequence (MUF) changes continuously because of the changing space weather conditions.

In this paper we discuss two approaches of estimating space weather effects on MUF. The first is based on the commercial ray-tracing program PropLab Pro[1], which uses the International Reference Ionosphere (IRI) to model ionospheric propagation conditions. Results from this method should be valid during quiet conditions, but as the used version of IRI takes into account only the long-term variability in the geomagnetic activity (sunspot number is one of the input paremeters), deviations from measurements are expected during disturbed conditions. The second method uses data from the Super Dual Auroral Radar Network (SuperDARN), in our case from the Co-operative UK Twin Located Auroral Sounding System (CUTLASS) radar located at Hankasalmi, Finland. Ground backscatter seen by these radars can be used to estimate ionospheric critical frequencies and thereby MUFs over large areas in the radar field-of-view. After describing the SuperDARN instrumentation we will discuss the methods used to extract HF propagation parameters from the radar data. This will be followed by a comparison of results obtained by the two methods outlined above. Finally we will summarise the obtained results and discuss possible future modifications.

INSTRUMENTATION

SuperDARN is a network of HF coherent scatter radars, designed to study plasma convection and irregularities over the auroral regions. A thorough description of SuperDARN radars is given by [1], here we give only a brief overview. The CUTLASS radar located at Hankasalmi (62.3° N, 26.6° E) is the most easterly of SuperDARN radars in the northern hemisphere. It was built by the Leicester University, UK, and has been in use since the end of February 1995. The radar consists of two antenna arrays, a main array of 16 antennas with both transmit and receive capability and an interferometer array of 4 antennas with receive capability only. The radar can operate in the HF frequency band between 8 MHz and 20 MHz. Appropriate phasing of the main array antennas creates 16 narrow beams, each covering only about 4°, the total azimuthal coverage being 52° about the radar boresight of -12°.

In addition to this frontal lobe, a symmetrical back lobe also exist. Although the antenna gain is over 10 dB smaller for both backward transmission and reception, better propagation conditions over mid latitudes can cause a considerable amount of ground backscatter from this direction, as pointed out by [2] and [3]. Receiving strong backscatter from behind applies only to ground scatter, not echoes caused by ionospheric irregularities. This is because the ionospheric backscatter condition, the perpendicularity of the wave normal and the geomagnetic field, $\mathbf{k}\perp\mathbf{B}$, in an area of intense irregularities is much harder to achieve at lower latitudes. The field-of-view of the Hankasalmi radar is illustrated in Fig. 1.

[1] Homepage: http://www.spacew.com/www/proplab.html

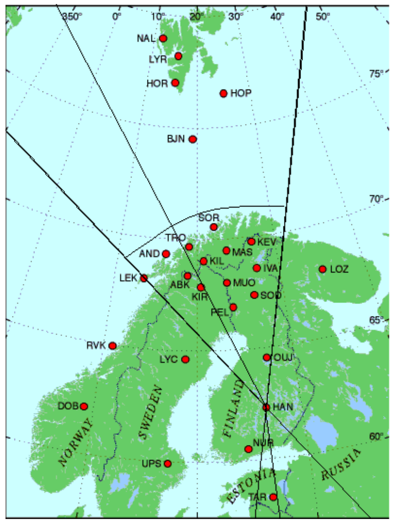

Figure 1: The Hankasalmi radar field-of-view. Direction of beam 5 and 1000 km ground distance are marked. The dots mark the IMAGE magnetometer stations.

In the normal mode of operation the 16 beams are sounded alternately, usinga a 6-second integration time per beam, producing field-of-view maps of backscatter every 2 minutes. Typically 75 range gates are sampled for each beam, with a pulse length of 300 μs, giving a resolution of 45 km and a lag of 180 km to the first gate. This gives a maximum range of approximately 3550 km for the radar.

PROPAGATION PARAMETERS

The main purpose of SuperDARN radars is to observe backscatter from decameter scale ionospheric irregularities. At least two other backscatter sources are also present, namely meteor trails and reflection from the ground. The main part of the wave power is reflected down from the ionosphere to the ground and, as the ground is not a perfect reflector, part of this power is scattered back to its arrival direction. Ground backscatter is distinguished from other echoes by its low Doppler velocity and low spectral width.

For simplicity we assume the ionosphere to be spherically stratified, unmagnetized and to consist of a single thin layer. In this simple case reflection from the ionosphere is determined by the plasma frequency f_p, transmission frequency f and angle θ between the horizontal and signal propagation direction at the reflection point. From geometrical optics we know that the condition for reflection is

$$(\cos\theta)^2 \geq 1 - f_p^2/f^2. \tag{1}$$

For a given frequency, larger angles θ correspond to shorter ground distances and propagation times. If $f > f_p$, rays with too large angles penetrate the ionosphere and there exists a shortest ground distance, the so called skip distance, for which radio communication is possible at this frequency. MUF for given transmitter and receiver sites is that frequency for which the skip distance matches the ground distance between these sites.

We can determine the length of the shortest propagation path from ground backscatter. If we further assume the reflection height, which is the virtual height of the E- or F-layer maximum electron density, we can calculate the angle θ for this signal by simple geometry. Using (1) we can calculate f_p and thereby the MUF for any given ground distance.

In this study we determined the shortest propagation path manually from the Hankasalmi radar summary plots. We used the distance corresponding to the closest continuous ground backscatter. A more refined method for range determination has been introduced by [4]. As final products we calculated the MUF for a 1000 km propagation path.

QUIET TIMES

We selected 22 geomagnetically quiet days from the year 1996 in order to compare the results obtained from ground backscatter with those obtained from the PropLab ray-tracing program. Quiet conditions were needed because the IRI model used by PropLab does not take geomagnetic activity into account. The activity level was determined by an estimate of the AE-index from the IMAGE magnetometer network, shown in Fig. 1. For a quiet day the daily average of AE

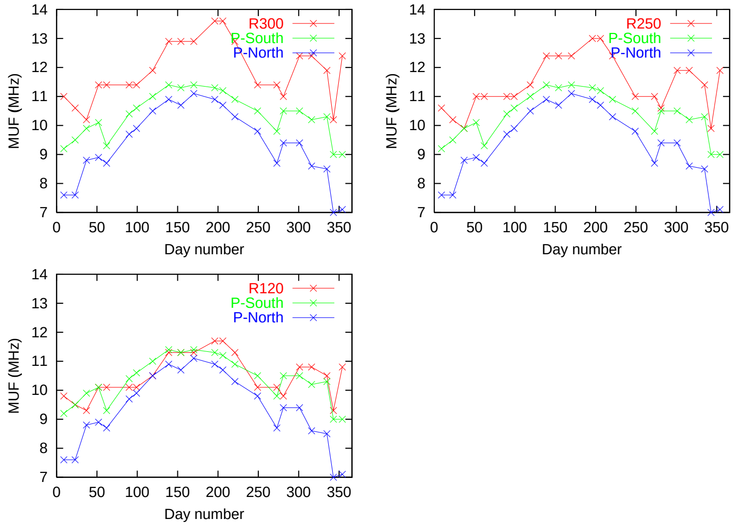

Figure 2: MUFs at 12 UT for selected quiet days in 1996 as determined from the Hankasalmi radar ground backscatter using different reflection heights (300, 250 and 120 km, corresponding to lines R300, R250 and R120 respectively) and by the PropLab program (lines P-South and P-North).

together with one-hour averages of AE during 11-13 UT should be below 50 nT. In some cases the condition for the daily average was relaxed, if high activity began in the evening, after 20 UT, say. We also tried to select days uniformly from the whole year, about two from each month, although this was not always possible.

We determined the nearest range gate of continuous ground scatter for each day at 12 UT from beam 5 of the Hankasalmi radar. From this we calculated MUF for a 1000 km communication link, as described above. The distance of the nearest ground backscatter varied between range gates 15 (800 km) and 22 (1150 km), lower values being observed during summer and higher values during winter. As a second method of MUF determination, we used PropLab to simulate the propagation conditions for these same days. PropLab uses a simplified 2-dimensional ionosphere in its MUF estimates. The ray-tracing engine follows rays of different frequencies and elevation angles, and determines the MUF and the corresponding angle by a homing technique.

The obtained results are summarized in Fig. 2. Two features complicate the use of ground backscatter. First, as mentioned above, a large part of the observed ground backscatter may originate at the backside of the radar. For example, examining the data used in a previous work [3], we found that in most cases southern backscatter dominated in the closest ranges. For that reason our MUFs based on radar data should correspond to a propagation path towards 179° (mirror image of beam 5) instead of -23° (beam 5). We used the PropLab to model both of these propagation paths and the results are shown as lines labelled P-North and P-South in Fig. 2. The other complication is the assumption of the reflection height. As pointed out by [5], for skip distace propagation this height should be only slightly larger than the height of maximum electron density in the reflecting layer. Our initial guess was 300 km for F-layer reflection, but IRI gives heights around 230-250 km. However, between March and September (day numbers 70-300), PropLab gives very low elevation angles for MUF propagation, indicating reflection from the E-layer. For this reason we have in Fig. 2 plotted MUFs calculated from ground scatter data using different reflection heights. Lines labelled R300, R250 and R120 correspond to reflection heights of 300, 250 and 120 km respectively.

Errors in the MUF determination introduced by the uncertainty in the reflection height are clearly visible in Fig. 2. Further errors arise from the determination of the propagation distance to the nearest backscatter location. As the range accuracy is 45 km, an error of ± 1 range gate (RG) may cause a noticeable error in the estimated MUF, namely 19$\pm$1 RG $\leftrightarrow$ 11.0$\pm$0.4 MHz if reflection height of 250 km is used. The best fit between MUFs from ground scatter and PropLab is achieved by assuming reflection from the E-layer and propagation in the southern direction, lines P-South and R120.

DISTURBED INTERVAL

Geomagnetic activity can seriously affect radio wave propagation, especially at high latitudes. To show these effects and the usability of SuperDARN radars in monitoring propagation conditions during disturbed intervals, we selected two nearby days, March 24 and 30, 1996, of different activity levels. The geomagnetic activity was high on the 24th,

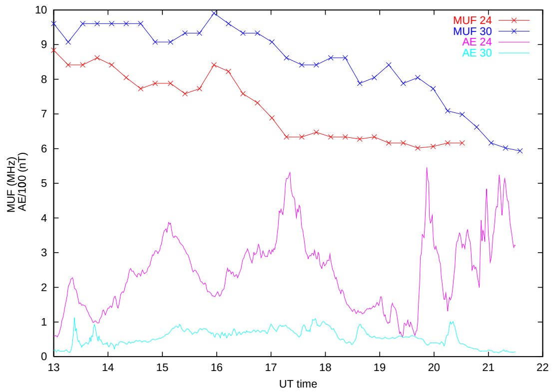

Figure 3: MUFs and AE-indices for a quiet day March 30 and a disturbed day March 24, 1996, at UT interval 13-22.

especially before 4 UT and after 15 UT, with a relatively quiet period in between. On the 30th it was quiet throughout the day. MUFs at roughly 15 minute intervals and AE-indices with a 1 minute resolution for these two days are plotted in Fig. 3. The distance of the nearest ground backscatter increased from about range gate 25 (1300 km) to about range gate 55 (2600 km) during the selected period 13-22 UT. Reflection height of 300 km was used in the MUF calculations.

During 13-17 UT the MUFs are similar for both days, although probably the high activity in the early hours of the 24th causes a small offset between the curves. With an increasing difference in the activity, also the difference in MUFs increases. The highest usable frequencies are notably lower during the whole of the disturbed day. Even the relatively quiet period around 19 UT is not long enough to increase the MUF back to the values of the quiet day. Continuous ground backscatter ended around 20:30 UT on the 24th and about 1 hour later on the 30th. After that only disperse ground backscatter was detected.

Although MUFs for the quiet and disturbed days are clearly different, there is no one-to-one correlation between the AE-index and MUF during the disturbed period. One should keep in mind, however, that AE and MUF monitor different ionospheric parameters, AE the currents and MUF the electron densities. In any case it should be remembered that an error of about ± 0.3 MHz is introduced because of uncertainties in range determination.

CONCLUSIONS

SuperDARN radars offer a possibility to monitor HF propagation conditions over wide areas at high latitudes. However, the uncertainties in the reflection height and propagation directions mentioned above complicate the direct use of ground backscatter data for this purpose. Considerable amount of backscatter seems to originate from behind the radar and is reflected from the E-layer. If this is not taken into account, serious overestimates of MUFs may result, as the backlobe of the radar usually points towards lower latitudes where propagation conditions are better. Furthermore, the use of too large reflection height increases MUF, as is visible in Fig 2. One possible solution is the use of interferometric data. Firstly, this would give us the elevation angle of the backscattered rays, thus enabling the direct determination of the reflection height. Secondly, the separation between echoes originating from forward and backward directions can be made using interferometric data, as explained by [2].

In addition to MUFs, also reflection heights and corresponding ionospheric plasma frequencies could be given, as these quantities are easier to compare with other observations (e.g. with ionosonde data).

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