CORRELATION OF NIGHTTIME MF SIGNAL STRENGTH WITH SOLAR ACTIVITY

Hiroki KOHATA, Iwane KIMURA
Department of Electrical Engineering II, Kyoto University, Kyoto 606, Japan

Tadahiko OGAWA
Communications Research Laboratory, Koganei, Tokyo 184, Japan

Noboru WAKAI
Institute of Research and Development, Tokai University, Tokyo 151, Japan

1 Introduction

Long distance propagation characteristics of nighttime MF broadcasting signals have been investigated especially in order to construct a base for frequency allocation planning in the MF band. Measurements were made in various areas (North America, Europe, Australia and etc.) of the world, and consequently, the standard propagation curves were obtained in each area. From these measurements, it was found that nighttime MF signal strengths depend on solar activity. This dependence is negative correlation and its tendency is greater in North America than in Europe but is negligible in the tropical latitudes [1].

In Japan, Communications Research Laboratory of Ministry of Post planned to measure Japanese MF broadcasting signal strength(774/770 kHz) propagating in north-south path crossed the equator over a decade on board Japanese antarctic ice breaker "Fuji". From the measurements, an interesting positive correlation of long distance propagating signal strengths with solar activity in the nighttime has been found. This result drew attention at CCIR, because the measurements of nighttime MF propagation characteristics made in North America had yielded a negative correlation of signal strengths with solar activity [2].

In this paper, we try to interpret the results of measurements on board Japanese ice breaker "Fuji" by using the multi-hop method with the full wave analysis, and the difference in correlation with solar activity between the results of "Fuji" measurements and those in North America.

2 Multi-hop Method

Propagation characteristics is computed by using the multi-hop method with full wave analysis. The multi-hop method is based on geometric optics. In this method, MF signal strength at a point is treated as the resultant of the fields created by different waves propagated directly from the transmitter in one or more hops. The total strength at this point is then the resultant of the field due to the wave diffracted by the ground and of the field due to the sky-wave. The sky-wave field is calculated from the free space propagation loss along the path and from the reflection loss at the ionosphere and the ground. For the n-th hop sky-wave, total reflection loss $\boldsymbol{R}_{\mathrm{t}}$ is represented by

$$\boldsymbol{R}_{\mathrm{t}} = \boldsymbol{R}_{\mathrm{i},n} \cdot \boldsymbol{R}_{\mathrm{g}} \cdot \boldsymbol{R}_{\mathrm{i},n-1} \cdots \boldsymbol{R}_{\mathrm{i},2} \cdot \boldsymbol{R}_{\mathrm{g}} \cdot \boldsymbol{R}_{\mathrm{i},1}$$

where

$$\boldsymbol{R}_{\mathrm{g}} = \begin{bmatrix} {}_{\parallel}R_{\parallel\mathrm{g}} & 0 \\ 0 & {}_{\perp}R_{\perp\mathrm{g}} \end{bmatrix}$$

is the reflection coefficient tensor of the ground surface and is determined by Fresnel reflection coefficient. And

$$\boldsymbol{R}_{\mathrm{i},n} = \begin{bmatrix} {}_{\parallel}R_{\parallel\mathrm{i},n} & {}_{\perp}R_{\parallel\mathrm{i},n} \\ {}_{\parallel}R_{\perp\mathrm{i},n} & {}_{\perp}R_{\perp\mathrm{i},n} \end{bmatrix}$$

is the reflection coefficient tensor of n-th reflection at the bottom of the ionosphere, which is calculated by means of the full wave analysis based on the multilayered technique developed by Nagano et al. [3]. The anisotropy of the ionosphere resulting from the earth's magnetic field is taken into account with IGRF model at the n-th reflection point.

In order to take account of conductivity of the earth and curvature of the earth surface, the cut-back factor is considered for ground wave propagation and sky-wave propagation over the horizon [4].

3 Numerical Results

Kuriki et al. [5] tried to interpret the results measured on board "Fuji", which indicate positive correlation of MF signal strength with solar activity, by using the multi-hop method with ray tracing technique estimating the absorption of sky-wave in the ionosphere instead of the full wave analysis calculating the reflection coefficient of the ionosphere. They assumed two different nighttime electron density profiles of the Chapman types, representing the solar maximum and minimum period, and obtained propagation curves of each period, which well explain the measured positive correlation.

We tried to compute the propagation curves by using our multi-hop method with the full wave analysis on the same electron density profiles and obtained the same curves and correlation.

However, a question remains how the negative correlation found in North America can be explained. To elucidate this problem, we set up the nighttime electron density profiles based on the following assumptions.

1. There is a ledge around an altitude range from about 85 to 90 km in the electron density profile of the lower ionosphere, even in the nighttime.
2. The electron density with this ledge structure is always greater in the maximum solar activity period than that in the minimum period.
3. The electron density corresponding to this ledge is greater in the low latitude region than in the middle and high latitude region.

These assumptions can not be completely verified for their validity, but as for the ledge structure of electron density, there were several rocket observations of the lower ionosphere before sunrise [6], which indicate a possibility of an existence of the ledge during midnight.

Now let us consider two electron density profiles corresponding to the solar maximum(solid curve) and minimum(broken curve) period as shown in Fig.1, in which N_r is the electron density that is able to reflect back the MF sky-wave of interest. Then, as shown in Fig.1, in the solar maximum period, the MF sky-wave is reflected at a height of $h_{\max}$ below the ledge, whereas in the minimum period, the sky-wave is reflected at $h_{\min}$ above the ledge. The propagating path in the ionosphere becomes longer in the solar minimum than in the maximum period, so that field strength on the ground of the MF sky-wave signal at a long distance is expected to be stronger in the maximum solar activity period than in the minimum period, that is a positive correlation.

On the other hand, in the middle latitude region, the electron density of such a ledge even in the solar maximum period is assumed to be less than the electron density N_r reflecting the MF sky-wave of interest. The electron density profiles (solid curve corresponds to the solar maximum period and broken curve to minimum period) are illustrated in Fig.2. Then, the sky-wave is reflected back at a height above the ledge, and the reflection height are almost same both in the solar maximum($h_{\max}$) and minimum($h_{\min}$) period. Such a situation results in a larger absorption in the solar maximum period than in the minimum period, because the electron density below the reflection height is greater in the solar maximum period than in the minimum period, resulting in a negative correlation of MF sky-wave strength with solar activity.

In the following, we will estimate MF sky-wave strength at long distances by using the multi-hop method with the full wave analysis for the calculation of reflection coefficient, in order to confirm the above scenario.

[1] Positive correlation case

The electron density profiles used for an interpretation of the results measured on board "Fuji" are shown in Fig.1. The results of the theoretical calculations are drawn by solid and broken curves for the solar maximum and minimum period respectively in Fig.3 together with the measured value (× denotes measured value in the solar maximum period and ○ in the minimum period). A good agreement between the measured and calculated characteristics is evident especially at a long distance of propagation, so that the scenario mentioned previously is proved to be appropriate.

[2] Negative correlation case

In North America, there are many examples of data which show the negative correlation of MF signal strengths with solar activity [2]. Out of them, 5 paths are picked up. Relative field strengths in the solar minimum period to that in the maximum period are shown as the histogram in Fig.4 together with measured relative strengths, where the symbols A to E corresponding to the 5 paths. In Fig.4, except path A and E, calculated relative field strengths well agree with measured relative strengths and denote negative correlation. On path A, slant distance is very short, and on path E, frequency is higher than others, so that N_r are greater than the assumed. Therefore our results for in North America are consistent with our previously mentioned scenario.

4 Conclusion

It is concluded that the measured correlations of nighttime MF signal strength with solar activity are well explained by the previously mentioned assumptions on the electron density profile. Positive correlation or negative correlation is determined by the relative relation between the electron density of the ledge and that necessary to reflect the sky-wave.

Acknowledgements

The authors would like to express their sincere thanks to Professor I. Nagano of Kanazawa University for kindly providing of the full wave analysis computer program developed by his group. The authors are deeply indebted to Professor M. Mambo of Kanazawa University and Professor I. Nagano for their helpful discussions.

References

[1] CCIR Report 1014, "Prediction of sky-wave field strength for broadcasting in region 2 in the band 1605-1705 kHz," Geneva, 1986.

[2] J. C. H. Wang, "Prediction of medium-frequency skywave field strength in North America," *IEEE Trans. Broadcast.*, vol. BC-23, pp. 43-49, 1977.

[3] I. Nagano, M. Mambo and G. Hutatsuishi, "Numerical calculations of electromagnetic waves in an anisotropic multilayered medium," *Radio Sci.*, vol. 10, pp. 611-617, 1975.

[4] J. R. Wait and A. M. Conda, "Pattern of antenna on a curved lossy surface," *IRE Trans. Ant. Prop.*, vol. AP-6, pp. 348-359, 1958.

[5] I. Kuriki, S. IGI and N. Wakai, "Solar activity dependence of MF sky-wave field strength in the nighttime," *J. Radio Res. Lab.*, vol. 35, pp. 43-56, 1988.

[6] L. Thomas and M. D. Harrison, "The electron density distributions in the D-region during the night and pre-sunrise period," *J. Atmos. Terr. Phys.*, vol. 32, pp. 1-14, 1970.

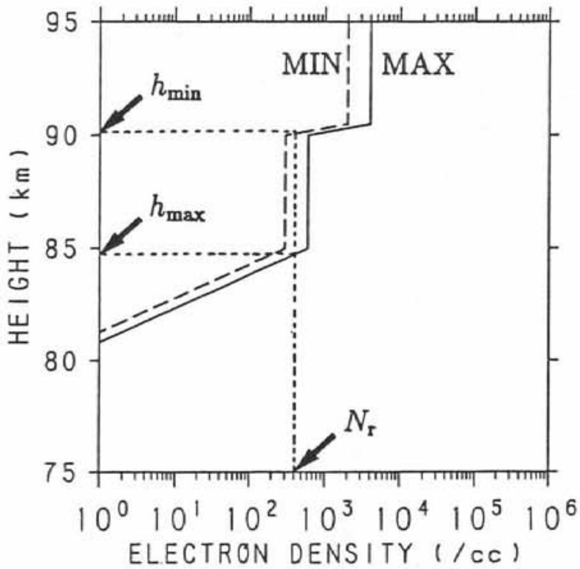

Fig.1 Electron density profiles ("Fuji").

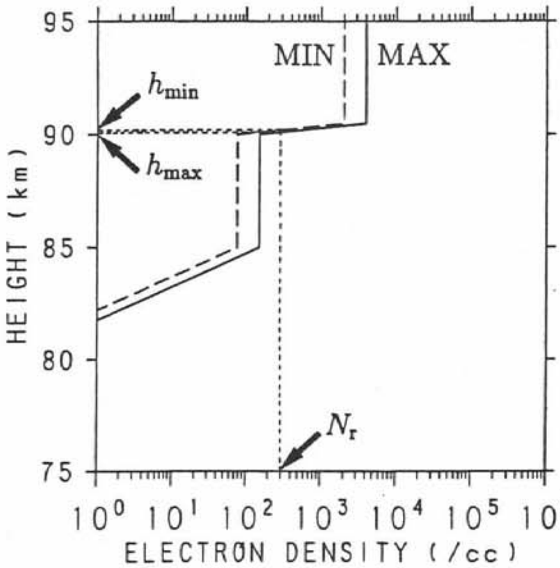

Fig.2 Electron density profiles (in North America).

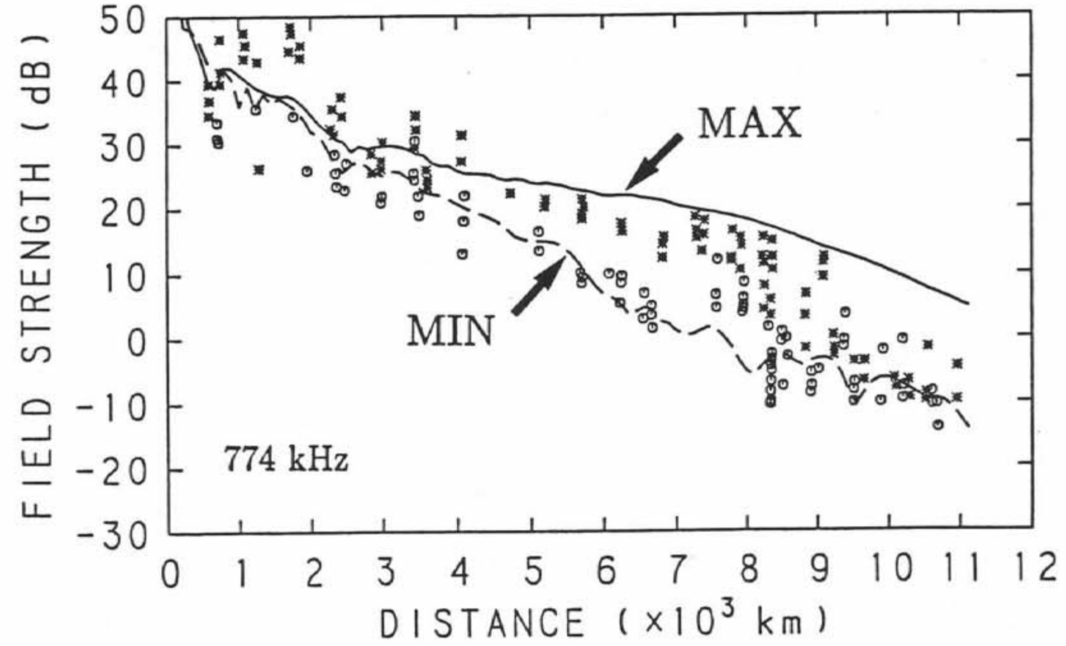

Fig.3 Computed propagation curves and measured value ("Fuji").

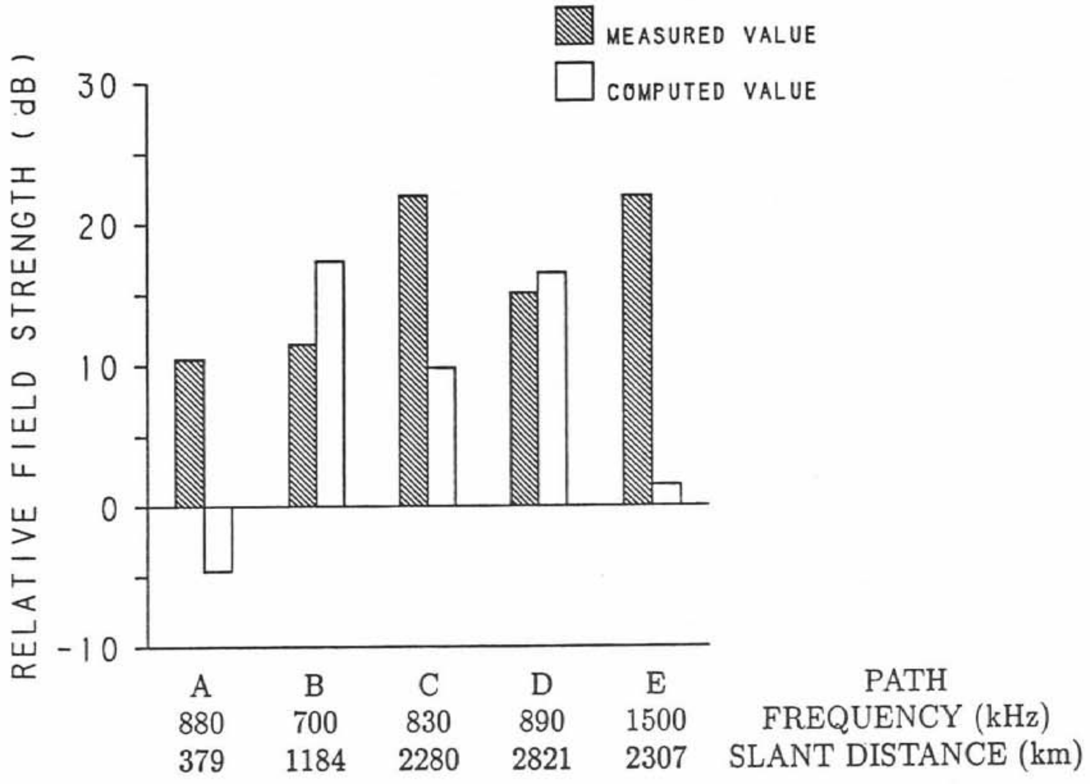

Fig.4 Computed relative field strengths and measured (in North America).