Seasonal Variations of Surface Radio Refractive Index in Mongolia

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In this paper, the statistical analysis of surface radio refractivity in Mongolia is studied. The method proposed in the recommendation of the International Telecommunication Union ITU has been used. Meteorological data derived from fifty nine weather stations which cover the most populated areas in Mongolia. A total of more than five million refractivity measurements was considered in this analysis. The result showed that the highest average values of the radio refractivity were observed in January while the lowest values were observed in April and May. The annual refractivity values were higher in the northern region and lower in the southern part of the geographical map. The monthly maximum radio refractivity value, 342 N-Units was in Zavkhan aimag in January. The lowest value was 290 N-Units in Umnugovi aimag in May. The result also shows that the seasonal refractivity variation is caused follows the climatic condition and geographical region.

Keywords: Radio refractive index, radio-wave propagation, meteorological parameters.

INTRODUCTION

During the design of radio communication networks, it is important to know the atmospheric radio refractive index, which is the ratio of the velocity of propagation of a radio wave in free space to the velocity in a specified medium. Radio wave propagation changes in the refractive index of air in the troposphere [1]. Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave. At standard atmospheric conditions near the Earth's surface, the radio refractive index is approximately 1.0003 [2]. Since the value of refractive index is almost unity, then the refractive index of air in the troposphere is often measured by a quantity called the radio-refractivity N, which is related to the refractive index, n as:

$$N = (n - 1) \times 10^6$$

As the conditions of propagation in the atmosphere vary, the interference of radio-wave propagation is observed. Such interferences are incident with some meteorological parameters (inversion of temperature, high evaporation and humidity, passing of the cold air over the warm surface and conversely). Radio waves travel through vacuum with a speed equal to the speed of light. In material medium, the speed of the radio waves is approximately c/n where c is the speed of light in vacuum and n is the radio refractive index of the medium. The value of the radio refractive index (n) for dry air is almost the same for radio waves and the light waves. But the value of the radio refractive index (n) for water vapor, which is always present in some quantity in the lower troposphere, is different for the light waves and radio waves. This arises from the fact that water vapor molecule has a permanent dipole moment which has different responses to the electric forces of different radio wave frequencies propagated within the atmosphere. The atmospheric radio refractive index depends on air temperature, humidity, atmospheric pressure and water vapor pressure. Subsequently, meteorological parameters depend on the height at a point above the ground surface. Variation in any of these meteorological parameters can make a significant variation on radio wave propagation, because radio signals can be refracted over the whole signal path [3]. Falodun and Ajewole [4] reported that in the atmosphere, pressure, temperature and humidity decrease exponentially as height h increases.

Radio frequency or radio wave signal propagation in the troposphere is affected by many factors which include the variations of meteorological parameters such as humidity, temperature and atmospheric pressure. Meteorological parameters are associated with the change in weather in different seasons of the year and these changes have resulted in refractivity changes. Grabner and Kvicera [5] reported that multipath effects also occur as a result of large scale variations in atmospheric radio refractive index, such as different horizontal layers having different refractivity. This effect occurs most often, when the same radio wave signals follow different paths thereby having different time of arrivals to its targeted point. This may result to interference of the radio wave signals with each other during propagation through the troposphere. The consequence of this large scale variation in the atmospheric refractive index is that radio waves propagating through the atmosphere become progressively curved towards the earth. Thus, the

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range of the radio waves is determined by the height dependence of the refractivity. Thus, the refractivity of the atmosphere will not only vary as the height changes but also affect radio signal.

In this paper, we estimate the seasonal variations of the radio refractivity using meteorological parameters (temperature, humidity and atmospheric pressure) for the station in Buyant-Ukhaa, Ulaanbaatar.

CALCULATION OF RADIO REFRACTIVITY

Radio refractive index, n, is equal to approximately 1.0003. Since n never exceeds unity by more than a few parts in 10^{-4}, it is convenient to consider scaled-up by 10^6 and measured by radio-refractivity N, which is related to the refractive index, n as:

$$N = (n-1) \times 10^6 \quad (1)$$

Radio refractivity [6] N is expressed by:

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (2)$$

with the dry term, N_{dry}, of radio refractivity given by:

$$N_{dry} = 77.6\frac{P}{T} \quad (3)$$

and the wet term, N_{wet}, by:

$$N_{wet} = 3.732 \times 10^5 \frac{e}{T^2} \quad (4)$$

where P is the atmospheric pressure (hPa), e is the water vapor pressure (hPa) and T is the absolute temperature (K).

The relationship between water vapor pressure e and relative humidity is given by [6]:

$$e = \frac{He_s}{100} \quad (5)$$

e_s is the saturation vapor pressure (hPa) at the temperature t (°C), and obtained from:

$$e_s = a\,exp\left(\frac{bt}{t+c}\right) \quad (6)$$

where H is the relative humidity (%) and t is the Celsius temperature (°C). For water a=6.1121, b=17.502, c=240.97 (valid between -20° to + 50°, with an accuracy of ±20%) [3].

RESULTS AND DISCUSSION

In this study, we investigated seasonal variation of refractivity over fifty nine localities. Meteorological data obtained from weather stations which located fifty nine different locations. These stations give us reasonable geographic coverage. Since temperature, humidity, atmospheric pressure and water vapor pressure, which are important parameters for determination of radio refractivity are highly variable and change rapidly in time and from place to place, measurements of these parameters were considered fifty nine different locations. Meteorological data were taken in different period for different stations. Twenty seven stations cover 40 years from 1960 to 2016 and rest of stations covers up to 32 years from 1974 to 2016. Each day, eight measurements of temperature, relative humidity and pressure were taken at 02.00, 05.00, 8.00, 11.00, 14.00, 17.00, 20.00 and 23.00 hours local time at all fifty nine stations. For this reason, the seasonal refractivity was calculated different periods for different stations. A total of more than five million refractivity measurements was calculated. The locations of the meteorological stations are shown in Figure 1.

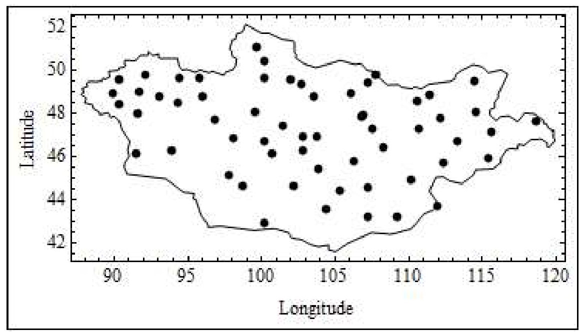

Figure 1. Location map for meteorological stations.

The refractivity values are estimated by using (2). The partial water vapor pressure e was determined by using (5) and (6). Dry term, N_{dry}, and wet term, N_{wet}, of refractivity were determined by using (3) and (4) respectively.

Figure 2 presents a typical variation of mean annual refractivity across Mongolia. The contours were calculated using mean annual refractivity values of 59 meteorological stations and altitudes of meteorological stations were not considered in the calculation. The result showed that northern region of geography has more higher refractivity value than the other regions. The maximum refractivity value was 320 N-units, observed in Rinchinlhumbe and Baruunturuun. These two stations fall within the same geographical and climatic region (the Khangai and Khuvsgul mountain areas). From the result, we can see that Gobian zone has lower refractivity values. This can be explained by the average annual precipitation. The average annual precipitation is low (around 38mm) in the Gobian zone and higher (around 389mm) in the Northern region [6]. The minimum refractivity value was observed in Gurvan-tes, 301 N-units.

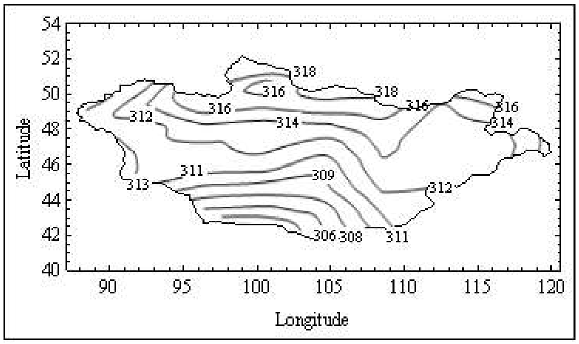

Figure 2. Annual mean N contours for Mongolia.

Contours of winter months (December, January and February) values of refractivity are shown in Figures 3, 4 and 14 respectively. It is seen that the refractivity values of winter months are higher than the annual mean values (Figure 2). The average values in Gobian zone were between 312 N-units and 320 N-units, while the average values in the colder region (Northern and Western region) were between 325 N-units and 336 N-units. The refractivity values in January were higher than all other months. From the geographical point of view, the refractivity values in winter months are higher in Northern region which is similar to annual values.

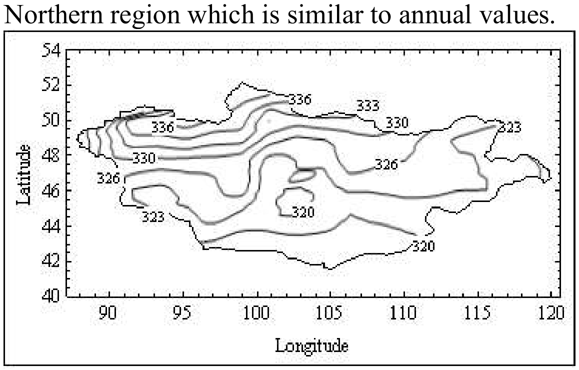

Figure 3. January mean N contours for Mongolia.

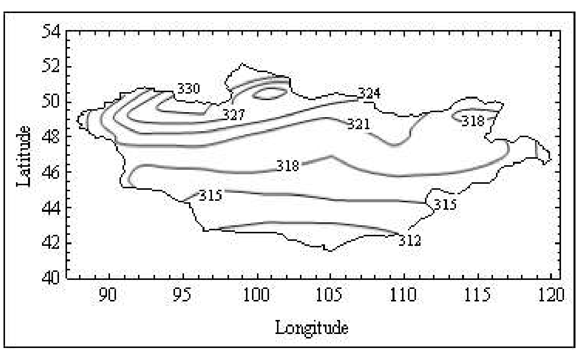

Figure 4. February mean N contours for Mongolia.

Plots of March, April and May values of refractivity are shown in Figure 5, 6, and 7 respectively. Figures 6 and 7 shown that the general behavior of the contours and refractivity values for April and May are similar to each other. Also, the refractivity values of these two months are lower than the annual mean values. Refractive values in March are higher than these two months.

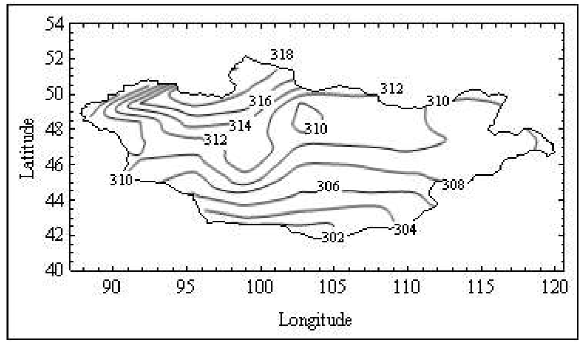

Figure 5. March mean N contours for Mongolia.

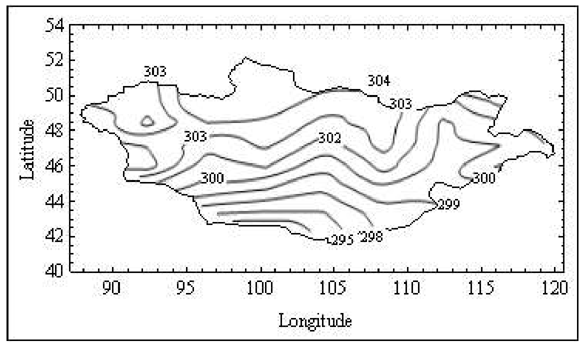

Figure 6. April mean N contours for Mongolia.

Charts of the mean values of radio refractivity in June, July, August and September (which are warm months and also the average precipitation is higher in these months) are presented in Figs. 8 to 11. From these pictures, we can see that the behavior of the contours is identical to each other. However, the refractivity values are higher in July while lower in September.

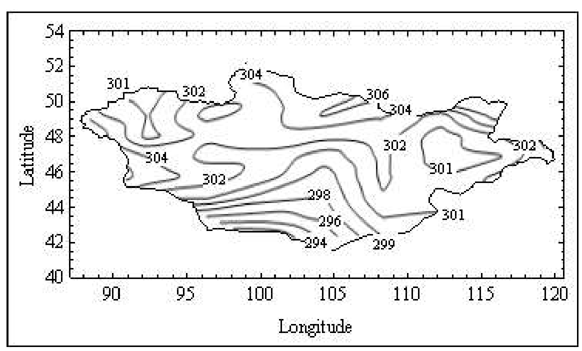

Figure 7. May mean N contours for Mongolia.

The interesting result observed in these warm months is that the refractivity values in the northern region and the southern region were same. Also, the highest refractivity values (325-329 N-Units) were in the eastern region in July and August.

The refractivity values increased from 304 N-Units (in the southern region) to 328 N-Units (in the eastern region) in August. The difference is 24 N-Units which is the highest of all months.

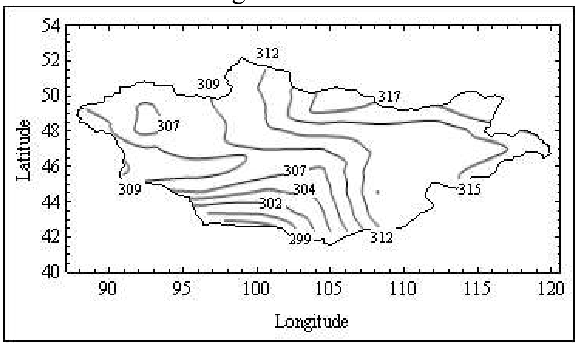

Figure 8. June mean N contours for Mongolia.

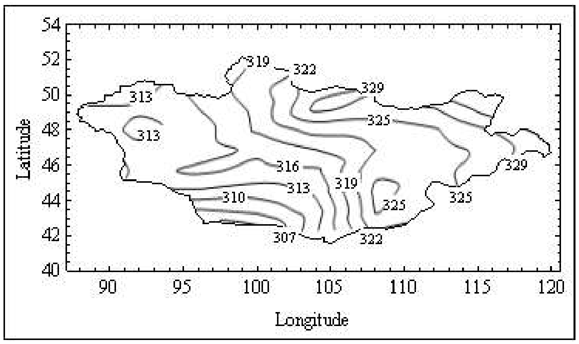

Figure 9. July mean N contours for Mongolia.

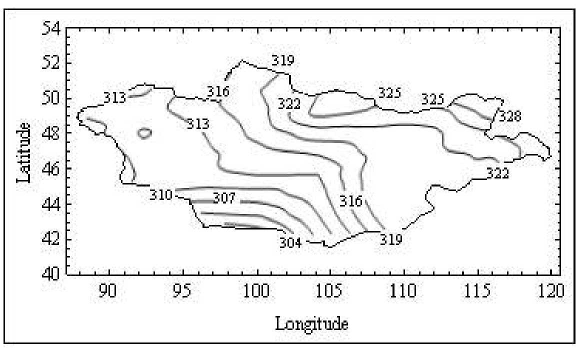

Figure 10. August mean N contours for Mongolia.

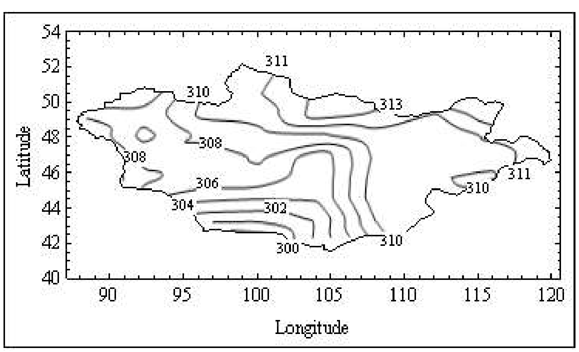

Figure 11. September mean N contours for Mongolia.

The radio refractivity values in October and November are depicted in Figure 12 and 13. Comparing the values of these two months, higher values were occurred in November. Also, the refractivity values increased from the southern region to northern region. From the Figure 12, we can see that lowest refractivity value is 320 N-Units in the southern region while the highest value is 310 N-Units in the northern region and variation of refractive values is only 10 N-Units which is the lowest of all other months.

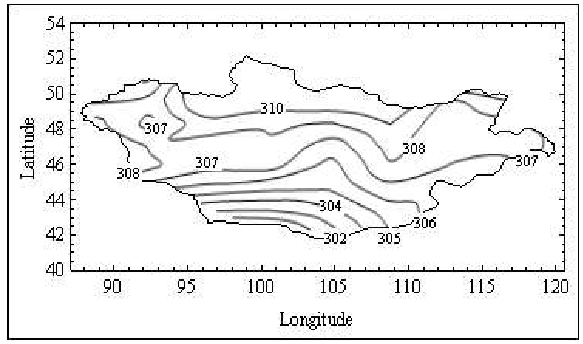

Figure 12. October mean N contours for Mongolia.

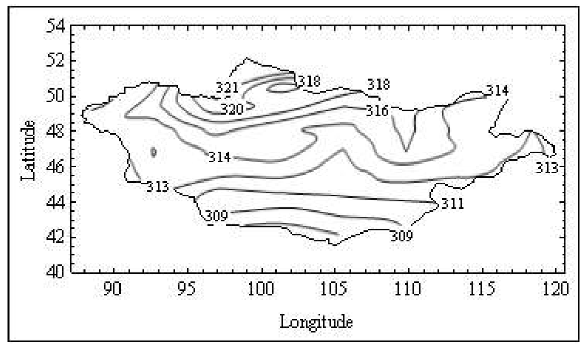

Figure 13. November mean N contours for Mongolia.

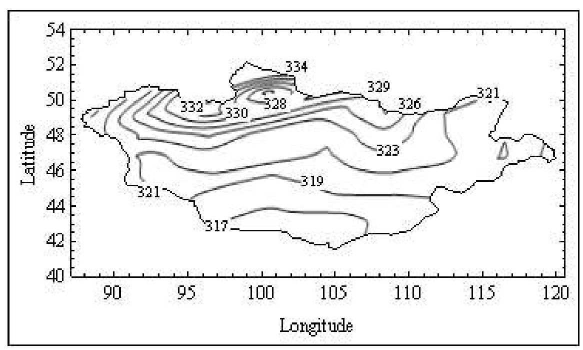

Figure 14. December mean N contours for Mongolia.

Figure 15 shows that the annual mean refractivity values for all localities. The vertical bars indicate the standard deviations of the refractivity values. It is seen that the $N-$ values vary in the wide range in the localities which placed in the northern region than the southern region.

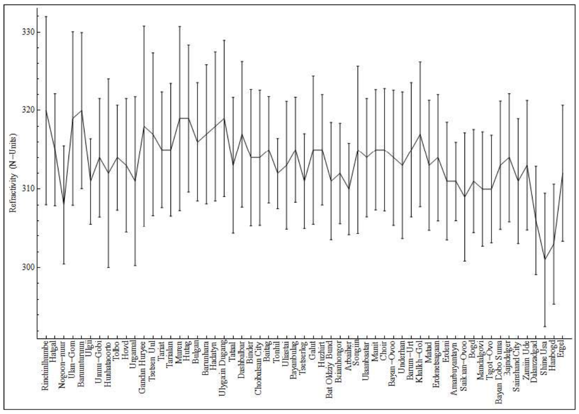

Figure 15. Annual N values for all stations. Vertical bars indicate the standard deviations of N for the stations.

CONCLUSION

In this paper, the surface radio refractivity values estimated from the data recorded at the fifty nine weather stations in Mongolia was analyzed. The lowest refractivity values were observed in April and May while the highest values were observed in January (the coldest and the driest month of the year). The refractivity values were lower in the southern region and gradually increased to the northern region except June, July, August and September. The refractivity values increased from the western region to eastern region while the values were same in southern and northern region for these four months. In addition to these comments and discussion, the following points can be emphasized:

- Higher variations were in northeast localities, although lower variations observed in southern localities.
- Higher mean refractivity values were in the Northern region in winter, spring and fall whereas eastern region in summer.
- Lower monthly and annual mean refractivity values were in Gobian zone.
- The lowest change in refractivity values was October. The refractivity values changed from 302 N-Units to 310 N-Units. While the highest change in refractivity values was in August. It changed from 304 N-Units to 328 N-Units.
- The monthly maximum radio refractivity value, 342 N-Units was in Zavkhan aimag in January. The lowest value was 290 N-Units in Umnugovi aimag in May.

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