Surface Radio Refractivity of Akure and Ondo town, South-west Nigeria.

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Abstract

The surface radio refractivity, refractivity gradient at 1km above ground surface and the effective earth radius factor, K over Akure and Ondo town of South west Nigeria has been investigated using Ten(10) years daily data of the meteorological parameters of Pressure, air temperature and humidity. The result showed that the mean monthly value of the surface refractivity at the Ondo station is generally slightly higher than that of Akure. The monthly mean value of refractivity at the two stations was found to be strongly correlated with a value of 0.915. The most negative refractive gradient value observed at Ondo and Akure are of -46.48N-units/km and -45.64N-units/km respectively and the least effective earth radius factor, k value of 1.421 and 1.410 were observed at the station respectively. These results showed that the Ondo and Akure station were generally super-refractive. The Ondo station was however found to be slightly more super-refractive than the Akure station.

Keywords: Surface Refractivity, Refractivity Gradient, Effective Earth Radius Factor, Super-refaction

Introduction

It is a well-established fact that radio wave in the Very High Frequency (V.H.F)., Ultra High Frequency (U.H.F)., and Super High Frequency (S.H.F) bands propagating through the troposphere can be greatly influenced by the variations in the tropospheric weather condition[1]. The tropospheric refractive index, n of the troposphere which affects radio wave propagation is dependent on the weather parameters of pressure, air temperature and humidity which are highly variable. The variability of these parameters can cause variation of the refractive index which affects the performance and electric field strength of the radio signals [2][3].

The variation of the refractive index in the horizontal direction is negligible compared with the vertical profile [4]. Large-scale variation of refractive index with height, and the extent to which it changes with time, are useful parameters for assessing the propagation characteristics of the troposphere which may vary greatly, depending on the type of air mass [1]. 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 range of the radio waves is determined by the height dependence of the refractivity [4]. According to [5], multipath effects also occur as a result of large scale variations in atmospheric radio refractive index having different horizontal layers of refractivity. Variations in vertical refractivity gradients change the propagation conditions to non-standard conditions which have serious implications with regard to signal loss, signal enhancement and anomalous propagation [6]

Two refractivity parameters are often encountered in estimating radio propagation effects; these are surface refractivity N_s and surface refractivity reduced to sea level *N*o [7]. The surface refractivity is very important in estimating the mean refractivity gradient in the first kilometer height above ground level. The radio refractivity gradient can be used to characterise refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting respectively. Another important atmospheric property which is also related to the refractivity gradient that can be used to characterize refractive conditions is the effective earth radius factor (K-factor). K-factor is defined as the ratio between the effective and actual earth radius. Under normal atmospheric conditions, K is approximately 4/3 [8].

Knowledge of the temporal and spatial variations of surface refractivity Ns is important for good planning of terrestrial radio links over a region [9]. [10] reported on variations of refractivity gradient and K-factor at 200 m altitude over Akure, Nigeria. However not much been reported on the radio refractivity over Ondo which is the second largest city in Ondo State after Akure. The aim of this study is to investigate variations of surface radio refractivity, refractivity gradient within first kilometer above the ground surface and k-factor over Akure and Ondo town, south west Nigeria. The study also seeks to investigate the correlation of the radio refractivity of the two stations.

Study Area:

Akure is the largest city and capital of Ondo State, Nigeria. It has a coordinate of 7.2571° N, 5.2058°E and an elevation of 358m above sea level. Ondo on the other hand is the second largest city in Ondo State.

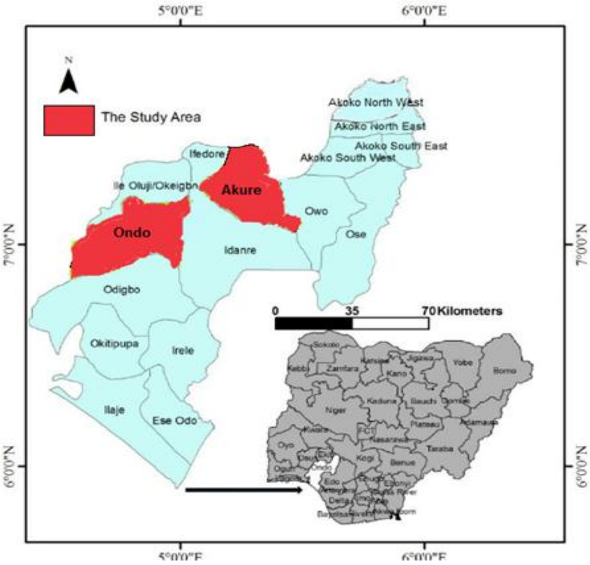

Fig. 1.0: Map of Ondo state showing the study area

It has a coordinate of 7.1000° N, 4.8417°E and an elevation of 287m above sea level. Both stations are located in the south-west geopolitical zone of Nigeria and fall within the same climatic region, that is, tropical rainforest. The two locations are about 43.77km apart. The Fig.1 shows the study locations.

Theory:

The Refractivity

At standard atmospheric conditions near the earth's surface, the radio refractive index (n) has a value of approximately 1.0003. In the design of radio systems, the use of a scaled-up unit of the variations in the values of the refractive index of air is more desirable. This scaled-up unit is called the radio refractivity (N) [11]. The radio refractivity, N is defined as the product of the refractive index, n less than one unit and one million. The N is related to the refractive index of the air as given by [12]:

$$N = (n-1) \times 10^6 = \frac{77.6\,P}{T^2} + \frac{3.73 \times 10^5}{T^2} \quad .. (1)$$

where P is the atmospheric pressure and T is the air temperature

The Clausius-Clapeyron relationship between water vapor pressure, e (hPa), saturation vapor pressure, e_S (hPa) and relative humidity, H (%), can, therefore, be deduced from the equation by [13]

$$e = \frac{H}{100} e_s \quad .... \quad (2)$$

where

$$e_s = 6.11\, exp\ \frac{17.26\,(T-273.16)}{T-35.87} \quad ....(3)$$

The Refractivity Gradient

The refractivity gradient, dN/dh is premised on the fact that the refractivity N varies with height above the ground surface due to the variations in the constituents' meteorological parameters of pressure, temperature and humidity with altitude. The radio refractivity gradient is used in the characterization of refractive conditions of the troposphere as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting respectively. The radio refractivity gradient value determines the anomalous behavior of microwave propagation in the troposphere [14]. Standard atmosphere is represented by an approximately linear decrease of refractivity at low altitudes with a long-term mean value of the refractivity gradient equal to –40 *N*/km [4]. Thus for normal refraction:

dN/dh = -40N-units/km

Under this condition, radio signals travel on a straight line path along the earth's surface and go out to space.

[15] gave the refractivity gradient conditions for anomalous propagation as follows:

For sub-refraction:

dN/dh > -40 N- unit/km

In this case, the N increase with height and the radio wave moves away from the earth's surface and the line of sight and range of propagation decrease accordingly.

For super-refraction:

dN/dh < -40N-units/km

Under this condition the N decreases with height and the radio waves are bent downward toward the earth. The degree of bending depends upon the strength of the super-refractive condition. If the atmosphere's temperature increases with height (inversion) and/or the water vapor content decreases rapidly with height, the refractivity gradient will decrease and radio waves will bend below the standard or normal path. This situation is known as super refraction, and causes the radar beam to deflect earthward below its normal path view. This generally causes the range of propagation of microwaves to increase accordingly.

For Ducting: dN/dh < -157

Under this condition, the waves bend downwards with a curvature greater than that of the earth. Radio energy bent downwards and can become trapped between a boundary or layer in the troposphere and surface of the Earth or sea (surface Duct) or between two boundaries in the troposphere (elevated Duct). In this wave guide-like propagation, very high signal strengths can be obtained at very long range (far beyond line-of-sight) and the signal strength may exceed its free space value.

According to [16], the mean refractivity gradient in the first kilometer height can be given by

$$\Delta N = -N_s\,(1-\exp(-1/h_o)) \quad \text{.................... (4)}$$

where Ns is surface refractivity and ho is a scale height.

The effective earth radius factor, K

The effective earth radius is the radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths follow straight lines while the heights and ground distance being the same for actual Earth with atmosphere and constant vertical gradient of refractivity [14]. k may be expressed in terms of refractivity gradient, dN/dh according to [12][14] as

$$K \approx \left[\frac{1}{1+\frac{dN/dh}{157}}\right] \quad \text{................(5)}$$

k, can be used to classify refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting. K values for the above refractive condition are given by [10] as follows:

If K = 4/3, it is standard atmosphere or normal refraction

If $4/3 > k > 0$, It is Sub-refraction

When $\infty > k > 4/3$, It is super refraction

Finally, If $-\infty < k < 0$, ducting occurs

For the purpose of this work we shall express the effective Earth radius factors as

$$K = \left[\frac{1}{1+\frac{\Delta N}{157}}\right] \quad \text{..(6)}$$

where ΔN is the refractivity gradient at 1km above the ground surface.

Materials and Methods

The data used for this work is a ten year daily data of surface air pressure, air temperature and humidity for the year 1997 to 2006 which is obtained from the Nigeria Meteorological Agency. The saturated vapour pressure e_s and the vapour pressure were calculated using equation (3) and (2) respectively. The surface refractivity, N_s for the Akure and Ondo station was calculated using equation (1). The Pearson correlation was used to determine the level of relationship between the refractivity at the two stations. The refractivity gradient for both stations was calculated using equation (4). The values of the effective earth radius factor, K for the study stations were calculated using equation (6). The monthly mean values of the refractivity, refractivity gradient and effective earth radius factor, K were found and used for the analysis.

Result and Discussion

Variation of Surface Refractivity, Ns

The monthly mean variation of refractivity in Akure is shown in fig.2. The refractivity in Akure is observed to increase sharply from its lowest value of 342.86N-units in the month of January to its maximum value of 370.29N-units in the month of May and afterwards decreases gradually till August before rising slowly to another peak value of 368.35N-units in the month of October and thereafter decreases sharply through November.

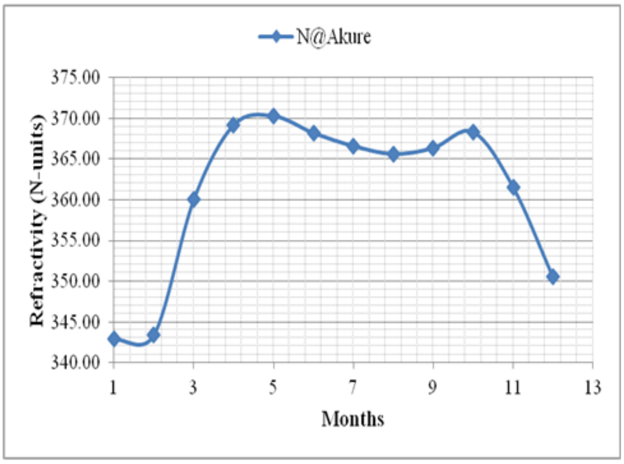

Fig. 2: Variation of Mean monthly surface refractivity value for Akure

The mean monthly refractivity value at the Ondo station was observed to increase slowly from its minimum value of 349.16N-units in the month of January through February and thereafter rose sharply through March to its maximum value of 375.22N-units in April; it however decreases slowly through the month of May till August before increasing gradually again through September to another peak value of 371.72N-units in the month of November and afterwards decreases sharply through December (see Fig. 3).

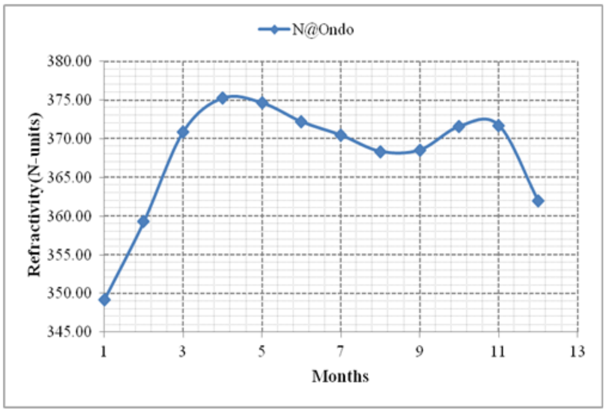

Fig. 3: Variation of Mean monthly surface refractivity value for Ondo

From the Fig. 2 and 3, it is seen that the refractivity has double peak at the two stations which occurred in the month of April/October and April/November at the Akure and Ondo station respectively. The occurrence of refractivity peak at the Ondo station in the month of November showed that the station experience intense rainfall at this time whereas at the Akure station the rainfall has drastically reduce at this same time due to the setting in of the harmattan or dry season in the area. This account for the lower refractivity value observed at the Akure station at this time. This also showed that the Ondo station experience longer period of intense rainfall period (April to November) than Akure (April to October). This period of intense rainfall (wet season) corresponds to the period when higher refractivity values were recorded at both stations. Lower refractivity values were observe between the month of November to March (dry season period) at Akure and from December to March (dry season period) at the Ondo station (see Fig. 1 and 2). The low refractivity values observed at this period is due to the cessation of rain and setting in of harmattan (dry, dusty and cold wind) at this time at both locations.

The variation of surface refractivity, Ns between the two stations is depicted in fig.4. The mean monthly value of the surface refractivity at the Ondo station is observed to be higher than that of the Akure station. The month of February is observed to present the highest difference of 15.84N-units while the month of September presents the least difference of 2.16N-units between the two stations.

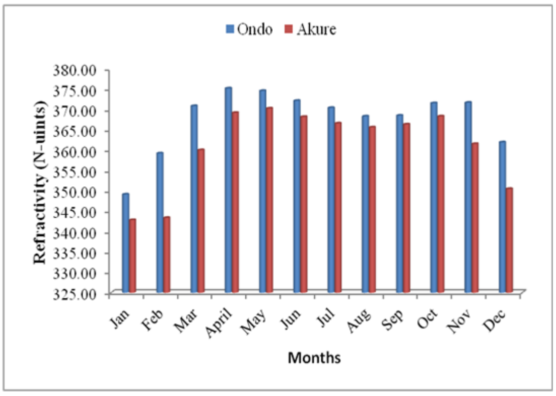

Fig. 4: Mean monthly surface refractivity variation for Akure and Ondo

The observed higher refractivity values at the Ondo station can be attributed to the lower temperature and higher humidity values recorded at this station compared to Akure station (see Fig. 5). The mean monthly value of the air pressure at the Ondo and Akure Station does not show much difference except for the month of February and September where Akure is seen to have conspicuously higher pressure values than Ondo (see Fig. 6).

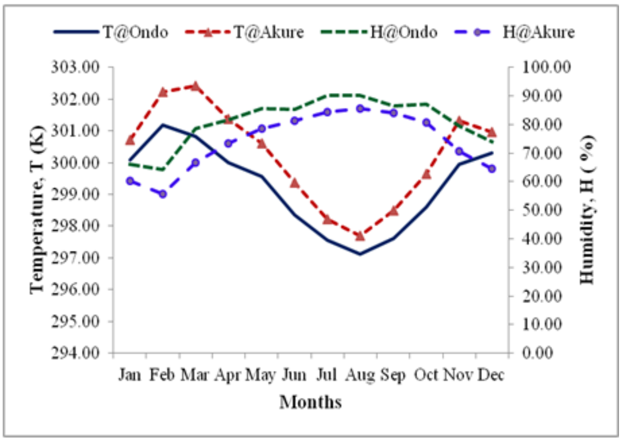

Fig.5: *Mean monthly values of temperature and humidity for Akure and Ondo*

For the Akure station, the average wet season (April to October) value of the refractivity is found to be 367.04N-units while the average dry season (November to March) refractivity value is found to be 349.21N-units. The average wet season (April to November) value of the refractivity is found to be 371.58N-units while the average dry season (December to March) refractivity value is found to be 360.32N-units at the Ondo station.

Correlation of Surface Refractivity

The fig.6 shows the scattered plot of the surface refractivity of Akure and Ondo. The R-square value (coefficient of determinant) of 0.8368 was obtained from the plot. Table 1 shows the mean, standard deviation, correlation and R-square value of the surface refractivity for the two stations. It is observed that Ondo has higher mean and lower standard deviation values compared to Akure. The Pearson correlation test on the surface refractivity of the two stations showed gave a value of 0.915 at 0.01 significant level. This result showed that the surface refractivity at the two stations are strongly correlated.

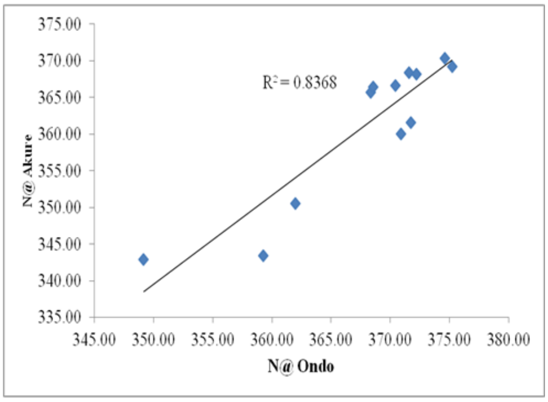

Fig.6: Scattered plot of refractivity at the two stations

Table 1: Descriptive stastistical Table of the Refractivity N

Station	Mean	Std. Dev.	No. of data	Pearson Correl.	R^2 value
Ondo N	367.82	7.52	12	0.915	0.8368
Akur e N	361.10	9.96	12		

Variation of Refractivity Gradient, ΔN.

The mean monthly variation of the refractivity gradient at the Akure and Ondo station is presented in Table.2. The most negative value of the refractivity gradient is observed to occur in the month of January at the two stations while the least negative value of the refractivity gradient occurred in the month of May at Akure while for Ondo it occurred in April. From the refractivity gradient values presented in the Table 2, it can be said that the two stations are super-refractive.

Table 2: Mean monthly values of refractivity gradient and effective radius factor

Months	ΔN(N-units/km) Ondo	ΔN(N-units/km) Akure	K @Ondo	K @ Akure
Jan	-46.48	-45.64	1.421	1.410
Feb	-47.83	-45.72	1.438	1.411
Mar	-49.37	-47.93	1.459	1.440
Apr	-49.95	-49.15	1.467	1.456
May	-49.87	-49.29	1.465	1.458
Jun	-49.54	-49.02	1.461	1.454
Jul	-49.31	-48.81	1.458	1.451
Aug	-49.03	-48.68	1.454	1.449
Sep	-49.06	-48.77	1.455	1.451
Oct	-49.47	-49.04	1.460	1.454
Nov	-49.48	-48.13	1.460	1.442
Dec	-48.19	-46.66	1.443	1.423
Ave. value	-48.97	-48.07	1.453	1.442

It is observed from the refractivity gradient values that the Akure station recorded slightly more negative values of the refractivity gradient compared to the Ondo station. The implication of this is that radio signal propagating through the troposphere will bend a little closer to the Earth surface at the Ondo station compared to the Akure station.

Variation of the Effective earth radius factor, K

The mean monthly variation of the effective earth radius factor, k is presented in the Table 2. The month of January is seen to have the least value 1.421 and 1.410 at the Ondo respectively and Akure station. The Month of April is seen to present the highest k value of 1.467 at the Ondo station while the Akure station recorded its highest K value of 1.458 in the month of May. Generally, the mean monthly value of K at Ondo is observed to be slightly higher than that of Akure. The observed K values at the two stations showed that the propagation condition is super-refractive at both station

Conclusion

The surface radio refractivity over Akure and Ondo has been studied and it was observed that the mean monthly values of the surface refractivity, Ns for the Ondo station were observed to be generally higher than that of Akure. The higher refractivity values observed at the Ondo station can be attributed to the lower temperature and higher humidity values recorded at this station compared to the Akure station. The average wet season refractivity value of 367.04N-units was recorded in Akure while the average dry season refractivity value was found to be 349.21N-units. The average wet season refractivity value for Ondo was found to be 371.58N-units while the average dry season refractivity value was found to be 360.32N-units. This result showed that electric field strength of radio signals in Ondo will be higher than that of Akure since according to [3], surface refractivity and electric field strength of radio signals are well correlated. The surface refractivity at the two stations was found to be strongly correlated with a value of 0.915. The refractivity gradient at Akure was found vary between -45.64N-units/km and -49.29N-uints/km while for Ondo it was found to vary between -46.48N-units/km and -49.95N-units/k. The earth effective radius factor, K was found to vary between 1.410 and 1.458 at Akure while for the Ondo station it was found to vary between 1.421 and 1.467. These results showed that both stations were super refractive. However, the Ondo station was slightly more super refractive. The implication of this is that radio wave propagating through the atmosphere will bend closer towards the earth surface at Ondo station compared to Akure.

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References:

Adediji A.T, Ajewole M.O, Falodun S.E.(2011) Distribution of radio refractivity gradient and effective earth radius factor (*k*-factor) over Akure, South Western Nigeria, Journal of Atmospheric and Solar-Terrestrial Physics Volume 73, Issue 16, Pages 2300-2304

Adediji A.T. and Ajewole M.O., (2008). Vertical profile of radio refractivity gradient in Akure south-west Nigeria. Progress in

Moses Ajewole, Adekunle Adediji, Joseph Ojo, Sunday Falodun, Kayode Adedayo,Theophilus Ewetumo, Ayodeji Ashidi, Samuel Adebusola, Kehinde Ogunjobi, Ayodeji Oluleye, Joseph Dada & Electromagnetics Research C, Vol.4, Pg 157-168**.**

Afolabi L.O., Seluwa E.O., Shogo O.E, Adebayo K (2018) Monthly Classification of Tropospheric Refraction and Duct Height Near Sea Level, Lagos State of Nigeria

Agbo G.O. Okoro O.N.,Amechi A.O.(2013), Atmospheri Refractivity over Abuja, Nigeria, International Research Journal of Pure and Applied Physics, Vol. 1, No.1, Pg 17-45

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering, Pg 81-86

Aremu Olaosebikan Akanni., Oyinkanola Lateef O.A., Akande Ademola., Azeez Waheed Adebayo (2018), Effect of Radio Refractivity Gradient and K-factor on Radio Signal Over Ibadan, Southwest, Nigeria, Global Scientific Journal, Volume 6, Issue 5, Pg 248-253

Ayantunji, B.G., Okeke P.N., J.O. Urama J,O; and Najib Y. (2011) A Semi-Empirical Model for Vertical Extrapolation of Surface Refractivity over Nigeria, The African Review of Physics, Pg 121-128

Edet C. O, Eno E. E, Ettah E. B, Kamgba. F. A. (2017) Seasonal Variation of Radio Refractivity in Calabar, Nigeria, International Journal of Scientific Research Engineering & Technology (IJSRET), Volume 6, Issue 6, Pg 670-673

Eichie J.O, Oyedum O.D, Ajewole M.O, Adediji A.T, Igwe K.C, Moses A. S (2015), Spatial Variability of VHF FM Radio Signals with Surface Refractivity Values in Niger State, Nigeria, Advances in Physics Theories and Applications, Vol.44, pg 99-106

Hall, M. P. M. (1979). "Effects of the Troposphere on Radio Communication". Institute of Electrical Engineers. Peter Peregrines Ltd. Stevenge UK..

Jaiyeola O. Paul and Abdullahi Ayegba (2018) Spatial Variation of Radio Refractivity Across Nigeria, International Journal of Scientific and Research Publications, Volume 8, Issue 5, Pg. 200-210

Olalekan Ojo (2020) Variation of Microwave Radio Refractivity Profiles with Temperature over Akure, Nigeria, Global Journal of Computer Science and

Technology: G Interdisciplinary, Volume 20, Issue 2 ,Version 1.0, pg 48-58

Ojo J.S., Adelakun A.O., Edward O.V(2019) Comparative study on Radio Refractivity Gradient in the troposphere using Chaotic Quantifiers, Heliyon 5 e02083.

Oyedum D.O. and Gambo G.K. (1994), Surface Refrativity of Northern Nigeria, Nigeria Journal of Physics, Vol.6, Pg 36-41

Oyedum, O. D. (2009): Seasonal Variation of Radio Field Strength and Radio Horizon in Nigeria. *Nigerian Journal of Pure and Applied Physics*, Vol. 5, pp. 97.

Pavel. Valtr, Pavel Pechac (2005), Tropospheric Refraction Modelling using Ray-Tracing and Parabolic Equation. Radio engineering, Vol. 14, No. 4, Pg 98-104

Richard J.Doviak, Dusan S. Zrnic (1993), Electromagnectic waves and propagation in Doppler Radar and weather Observations, second Edition, Academic Press,