

REFRACTIVITY GRADIENT STATISTICS FOR SINGAPORE OVER 7 YEARS

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1. Introduction

Radio wave propagation in the lower atmosphere is mainly affected by the variations of refractivity gradient along the radio link. For instance, the minimum *k-factor* (the effective earth radius factor) exceeded for a high percentage of time is useful for path clearance calculation while for interference prediction, the high or negative values of *k-factor* exceeded for a small percentage of time are essential. Therefore, it is necessary to understand the variations of refractivity gradient for accurate prediction of fading or interference signals. Unfortunately, there are little data on refractive index in the tropical countries that can be used to characterize the propagation condition in this region. To address this concern, several years of refractivity data for Singapore has been obtained and analyzed. The results can serve as a guide for the estimation of radio refractivity structure of countries in the same climatic region. In this paper, statistics of refractivity gradient in ground-to-100 m level of Singapore over 7 years are presented.

The data used are obtained from the radiosonde station located in the east of Singapore, at latitude 1.33°N and longitude 103.88°E, with altitude of 14 m above mean sea level. The data spans the period from 1993 to 1999, taken twice daily at 0000 GMT (0800 local time) and 1000 GMT (1800 local time). This gives a total of 4930 ascents after the missing or invalid data had been discounted. The ascents are referred as morning and afternoon ascents, respectively, in the following sections. The analyses utilize data at 50m-height interval, i.e. 14m (ground), 50m, 100m, 150 m and so on up to 2 km, instead of the commonly used standard pressure level. However, the results presented in this paper concentrate on those of the ground-to-100 m level, since this is the most important level, considering the local terrain profile and the typical antenna heights.

2. Climatic condition in Singapore

The tropical island situated at the southern part of Peninsula Malaysia is located 136.8 km north of the equator. Its climate is characterized by two main monsoon seasons that are separated by two relatively short inter-monsoon periods. The Northeast monsoon normally prevails from early December to March, with winds sometimes reaching 20 km/hr. It is often cloudy in December and January with frequent afternoon showers, but relatively drier in February till early March. From about April, the pre-Southwest monsoon starts, carrying light winds and early evening showers, often with thunder. By June, the Southwest wind is established and lasts until September or early October. During this time, late morning and early afternoon showers are common. The other inter-monsoon season then starts in October, carrying maximum rainfall, before the next Northeast monsoon arrives.

3. Refractivity gradient in the ground-to-100 m level

Refractivity, N , can be calculated from the radiosonde data using the standard equation [1]. With the values of refractivity at various height, the refractivity gradient, α , can then be found from:

$$\alpha = \frac{N_2 - N_1}{h_2 - h_1} = \frac{\Delta N}{\Delta h} \quad \text{NU/km} \quad (1)$$

where N_1, N_2 are refractivity values at heights h_1 and h_2 , respectively. The mean value of α is denoted by $\bar{\alpha}$ and its standard deviation by σ_α .

Various studies [2] [3] [4] had revealed that the refractivity gradients in the tropical countries are significantly lower than those found in temperate regions. Similar results are obtained in this paper, as seen from the probability distributions throughout the years considered. In the analysis, the statistics are calculated with a resolution of 5 NU/km. The cumulative probability distribution for four typical months, February, May, August and November, over the seven years, are shown in Figure (1). The lowest median values of each year and their corresponding k -factors are tabulated in Table (1).

The variations of refractivity gradient for each month over the seven years are shown in Figure (2). It can be seen that the $|\alpha_{95\%}-\alpha_{50\%}|$ variability is greater in June, September and November while smaller in January and February for morning ascent. The results of a study on a microwave link in Singapore [5] suggest that this variability indicate multipath-fading occurrences. Therefore, it is expected that multipath-fading probability would be higher in June, September and November, while lower in January and February. This is almost in line with expectation since June and September fall within the inter-monsoon (high rainfall) season, while January and February are dry months. As for afternoon ascent, the maximum variability occurs in September and minimum in January, almost similar to the morning ascent. It is worth noting that refractivity gradient often exhibits greatest variability during sunrise and sunset due to the extreme heating of the atmosphere at this time. Owing to the timing the balloon ascents, only the afternoon ascent data depicts closely the sunset condition, while the morning ascents do not coincide with sunrise. Hence, the results may underestimate the true variability in refractivity gradient for morning ascent.

4. The effective earth radius factor, k

In analyzing the terrain profile for radio system planning, it is essential to take into account the effective earth radius factor, called the k -factor. It can be found from the refractivity gradient using

the equation:
$$k = \frac{1}{1 + \alpha/157} \quad (2)$$

The low k values give an indication of the worst-case k -factor to be considered for path clearance design of microwave line-of-sight links. From the data, it is found that the values exceeded for 5% of the time are 0.85 (May) for morning ascents and 2.15 (August) for afternoon ascents. On the other hand, the values exceeded for 1% are 0.61 (June) and 1.11 (October) for both morning and afternoon ascents, respectively.

In temperate regions, the median value of k -factor (k_{med}) is taken as $4/3$ in radio system planning. However, the value may not be applicable to the tropics due to its extreme refractivity gradients. In fact, it is found that the values of k_{med} for morning ascent are much higher than $4/3$, with the exception of July and November. On the other hand, the median values for afternoon ascent fall below 0 NU/km in all months. Table (2) shows k_{med} for all the months over the first 100 m.

As a result of the great variability in refractivity gradient, the values of k -factor at 99% and 1% probability shown in Table (3) are worth noting. This gives a coarse indication of the propagation condition (sub-refraction or super-refraction) occurrence probability.

5. The probability of duct occurrence

The refractivity gradient in Singapore are very extreme compared to temperate countries – lower than 0 NU/km for more than 95% of the time. Hence it is expected that anomalous propagation occurrence are high. This can be seen from the probability of duct occurrence discussed in this section.

The ducting probability curves for the ground-to-100 m level over the considered years are shown in Figure (3). It is found that the probability in the afternoon is significantly higher than that in the morning, as expected. For the morning ascent, the highest probability occurs in July (50.46%) and the lowest in March (22.79%). For the afternoon ascent, the probability in May is maximum, reaching 92.27%, while the probability in December is minimum at 70.23%. However, it should be noted that results from Hu [5] reveal that the fading behaviours are not as serious as the k statistics suggest.

6. Conclusion

In this paper, the monthly refractivity gradients for the ground-to-100 m data over 7 years (1993 to 1999) are studied, separately for morning and afternoon ascents. The cumulative distributions and the $|\alpha_{95\%}-\alpha_{50\%}|$ variability of refractivity gradient are presented. The results reveal that the refractivity lapse rate is significantly higher in Singapore than in temperate regions. The variability also reveals the months with possible higher probability of multipath fading. From the refractivity gradient, the statistics of k -factor are computed. The values of the worst-case k are found, which can be used in path clearance design. The median k values are also obtained and it is found that the values for morning ascent are generally higher than 4/3, while all are below 0 NU/km for afternoon ascent. In the last section, the probabilities of duct occurrence are presented. In line with expectation, the probabilities are higher than those in temperate countries, especially for the afternoon ascent.

Acknowledgement

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Reference

- [1]. Bean, B. R. and Dutton, E. J., *Radio meteorology*, pp. 435, Dover, New York, 1968.
- [2]. Samson, C. A. and Maloney, L. J., "Observations of radio refractivity gradients in the Mekong Delta", *Radio Science*, Vol. 6, No. 12, pp 1027-1032, December 1971.
- [3]. Dhein, N. R., Pontes, M. S. and Silva Mello, L. A. R., "Statistical behaviour of refractivity gradient in the tropics", *Eighth International Conference on Antenna and Propagation*, Vol. 1, pp 340-343, 1993..
- [4]. Ong, J. T., "Seasonal variations of refractivity gradient for Penang, Malaysia", *MICC*, 1995.
- [5]. Hu, C. F., *Performance and multipath propagation modelling of a line-of-sight microwave link*, School of Electrical and Electronic Engineering, Nanyang Technological University, 1998.

Table 1. Minimum values of median refractivity gradient and corresponding k -factor

	1993	1994	1995	1996	1997	1998	1999
Morning	-135.0 (7.14) (Aug)	-156.3 (209.3) (Jul)	-147.5 (16.53) (Mar)	-180.0 (-6.83) (Jul)	-173.8 (-9.37) (Jan & Jul)	-188.8 (-4.94) (Nov)	-220.0 (-2.49) (Jun)
Afternoon	-247.5 (-1.73) (Aug)	-265.0 (-1.45) (Sep)	-240.0 (-1.89) (Jun)	-300.0 (-1.1) (May)	-272.5 (-1.36) (July)	-291.3 (-1.17) (Aug)	-290.0 (-1.18) (Jun)

Table 2. Values of k_{med} for each month over 7 years

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Morning	7.2	7.27	6.3	6	6.68	9.11	-66.1	7.3	7.14	8.91	-102	8.72
Afternoon	-2.43	-2.36	-2.43	-2.01	-1.78	-1.79	-1.67	-2.15	-2.23	-2.1	-2.45	-3.36

Table 3. Values of $k_{99\%}$ and $k_{1\%}$ for both ascents over 7 years

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AM	$k_{99\%}$	-1.13	-1.99	-1.28	-1.1	-1.28	-1.1	-1.03	-1.28	-0.98	-1.0	-1.0	-1.46
	$k_{1\%}$	1.18	1.13	1.0	0.74	0.66	0.61	0.97	0.81	0.69	0.69	0.97	0.82
PM	$k_{99\%}$	-0.77	-0.63	-0.68	-0.51	-0.58	-0.61	-0.51	-0.61	-0.47	-0.54	-0.74	-0.66
	$k_{1\%}$	1.89	1.77	2.2	1.41	2.05	1.71	2.12	1.35	1.63	1.11	3.03	1.48

Note: AM: morning ascent; PM: afternoon ascent

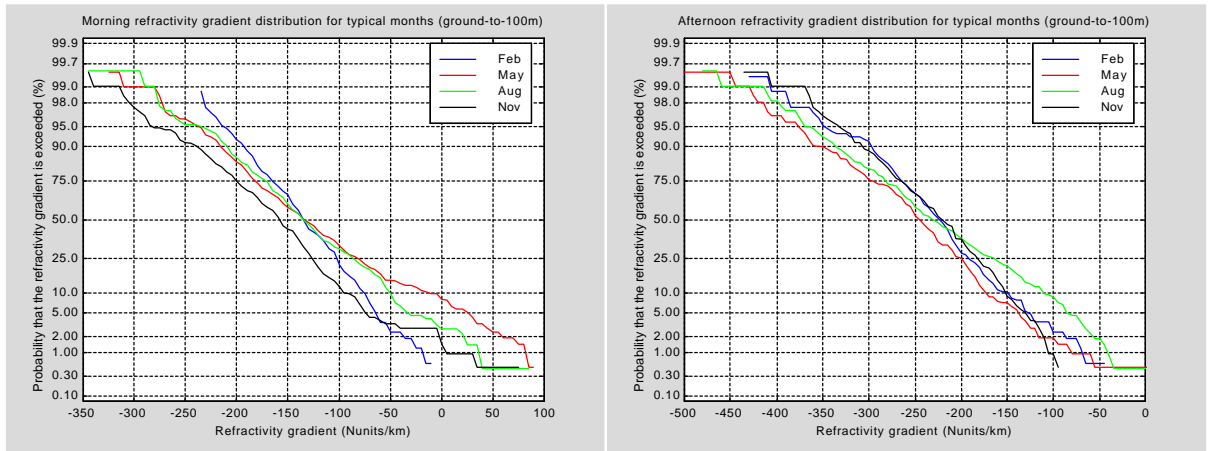


Figure 1. Cumulative probability distribution for February, May, August and November

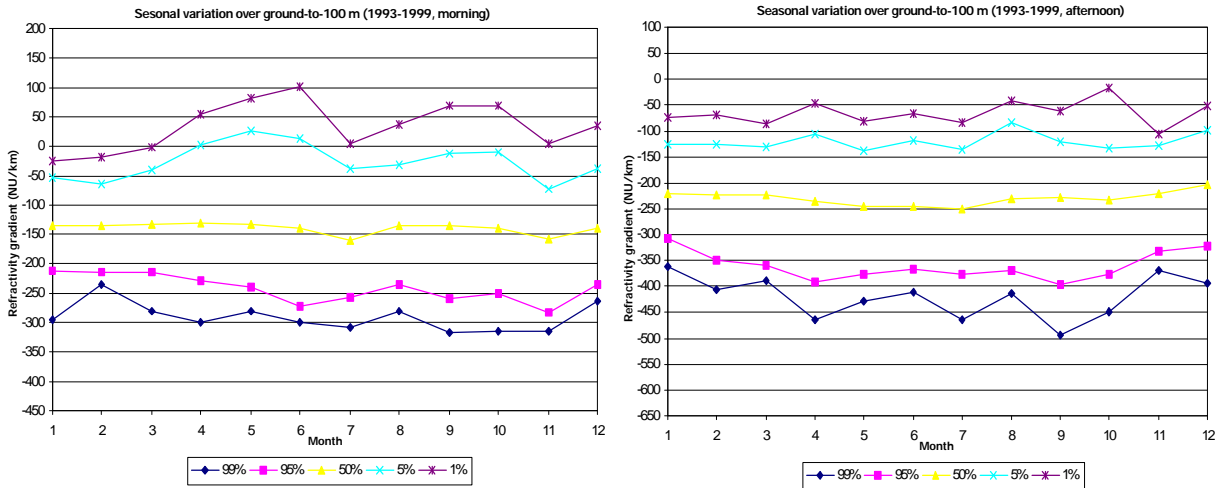


Figure 2. Seasonal variation of refractivity gradients

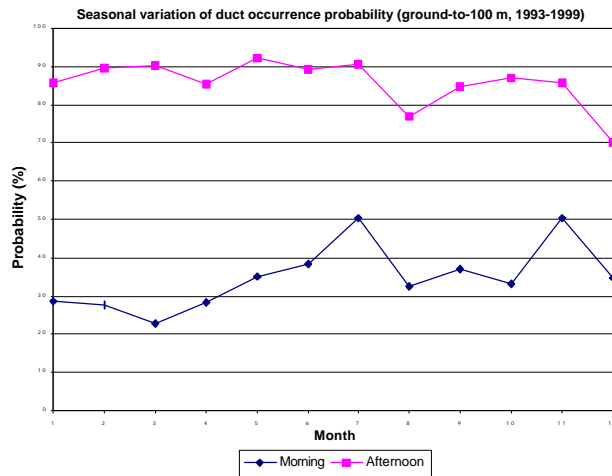


Figure 3. Duct occurrence probability for the first 100 m above ground