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Correlation Between Hourly Median Scattered Signals and Simple Refractivity Parameters

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Measured signals on two tropospheric scatter links have been analyzed in the light of radio refractivity profiles prepared from radiosonde data. On the shorter link (San Diego—Santa Ana, 85 miles) the basic transmission loss was found to be approximately a linear function of ΔN, the change in radio refractivity from the ground to a height of 1 kilometer. On the longer (Cape Canaveral—New Providence Island, Bahamas, 300 miles) the relationship between transmission loss and ΔN was nonlinear, and better results were obtained by averaging the refractivity gradient over 5,000 feet. Correlation coefficients on the San Diego—Santa Ana link range from 0.39 in August to 0.84 in February. On the Cape Canaveral—New Providence link the correlation factor is 0.92. The results show the feasibility of forecasting signal-to-noise ratios on over-water tropospheric scatter communications systems on a daily or hourly basis.

1. Introduction

The correlation of signal strengths in tropospheric scatter propagation beyond the horizon and weather conditions along the path was noted by a number of writers in the early 1950's. For example, Bullington et al., [1955] noted on a link in Newfoundland in 1953–54 that hourly median signal levels were depressed during snowstorms, but enhanced during foggy periods by 5 to 10 db. The changes appeared to be due to the fact that various weather situations are associated with characteristic distributions of radio refractivity, not only at the surface, but aloft. The vertical refractivity gradient would appear to be of particular importance, as it determines the amount of bending to which the transmitter and receiver beams are subjected, and hence the scattering angle and the height of the common volume for a given path.

The radio refractivity in N units is given by

$$N=\frac{77.6}{T}\left[p+\frac{4810e_w}{T}\right], \tag{1}$$

where $N=(n-1)\,10^6$, where n is the true radio refractive index, p is the pressure in mb, e_w is the water vapor pressure in mb, and T is the temperature in °K. Due to instrument lag, radiosonde observations are useless in measuring the small-scale fluctuations in N which actually scatter radio waves, but they are useful in determining the bending of radio beams.

A large amount of work relating L_B, the basic transmission loss on troposcatter links, to ΔN, the change in radio refractivity in the first kilometer above the surface, as determined from radiosonde data, has been carried out at the Central Radio Propagation Laboratory of the National Bureau of Standards. Bean and Meaney [1955] studied the correlations between the monthly median of the basic transmission loss and monthly median values of ΔN for 25 paths in various parts of the United States. For each path a linear regression was obtained of the form

$$L_B=a+b\Delta N. \tag{2}$$

The coefficient b showed a systematic variation with path length, with a typical value for it being 0.6 db. This is much larger than had been expected from a consideration of changes in the scattering angle alone [Norton et al., 1955]. Thus Bean and Meaney's results indicate that the scattering efficiency of the common volume is correlated with ΔN.

In their article, Bean and Meaney reported further that the surface refractivity, N_s, was compared with L_B in a number of cases and yielded almost as close a fit as ΔN. This is not surprising since ΔN and N_s are themselves highly correlated. The radio refractivity must approach zero at great heights, and so one would expect steep refractivity gradients in areas with high surface refractivity. This question has recently been explored in more detail by Bean and Cahoon [1961], who used values of ΔN computed by comparing N_s with N-values at heights ranging from 0.1 to 3 km. This detailed study serves to confirm the finding that N_s is, in general, as reliable a predictor of L_B as any refractivity gradient determined from radiosonde data.

2. Correlation of Scattered Signals and Refractivity Parameters: Cape Canaveral—New Providence Island

The success of Bean and Meaney in relating *monthly* median scattered signals to refractivity gradients and the observations of day-to-day variations in signal levels showed that it should be possible, at least on some links, to relate *hourly* medians to the weather conditions along the path. Bean [1956], in a study of transmissions from Dallas, found that the hourly median of the scatter signal received at Austin was correlated with the mean of the values of N_s observed at Dallas and Austin. The correlation coefficient ranged from 0.44 to 0.64 depending on the time of day. An attempt to correlate hourly medians on a path in Kansas with refractivity gradients and the thermodynamic stability of the atmosphere was reported by Misme [1958].

A good chance to investigate this possibility further was provided by a link operated between Patrick Air Force Base at Cape Canaveral, Florida, and New Providence Island, Bahamas, from late 1956 to early 1958 by the University of Florida. This is an over-water path, which means that diurnal variations were at a minimum. Three radiosonde stations were located on or near the path. The path length (300 miles) ensured that the signals received were due to scatter and did not contain any significant component of diffracted power. In this test operation, pulsed signals at 1,262 Mc/s were transmitted from Cape Canaveral and received at New Providence Island. At the receiver the signals were sorted into 30 levels and automatically recorded. Equipment and operational details are given in the final report on the project by Latour [1959].

The study by the University of Florida was concerned with relating day-to-day performance of the link to weather conditions. No diurnal effects were detected. Signal levels were higher in summer than in winter. The most marked changes occurred with cold frontal passages, which sometimes produced drops of 15 db in 2 or 3 hr.

Although the link was in operation for more than a year, most operations were on a nine-to-five o'clock basis. Regular radiosonde observation times in the Eastern Time zone are 0700 and 1900 hours. Fortunately, the link was occasionally operated on a 24-hr basis. We selected for detailed study three periods of such records, in August, October, and December of 1957. They yielded 60 median signals computed over 2-hr intervals which have been compared with radiosonde data.[1] As the monitor system used showed the variations in transmitter power to be less than 0.5 db, the received signals can be considered as varying inversely with the transmission loss over the path.

Various weather parameters were compared with the median signal levels; we now present the three yielding the highest correlation. Figure 1 is a scatter diagram of the received power, P, versus the mean of the surface refractivity at the end points, N_s. The correlation coefficient is 0.85. The close correlation between P and N_s for this link was noted in Latour's report. The regression coefficient for the least squares fit is 0.30 db per unit change in N_s. This is larger than some values recently quoted for other paths [Onoe et al., 1958; Bean et al., 1960] but smaller than the coefficient calculated by the present author using data from the New York–New Jersey area as presented by Crawford et al., [1959].

[1] In order to get a fair representation of winter cases, some refractivity profiles for 0100 and 1300 hr were prepared using surface observations, which are made every 6 hr, and interpolated upper air data.

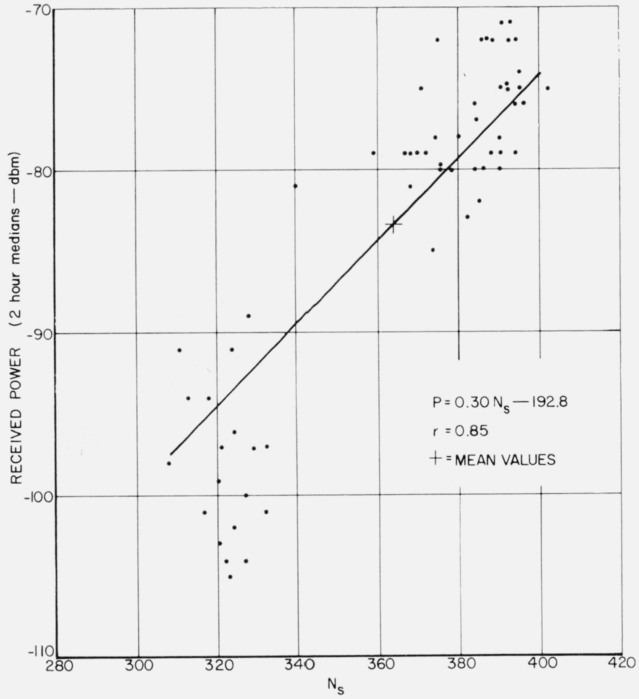

FIGURE 1. *Received power versus mean refractivity at end points (Cape Canaveral—New Providence Is.).*

Figure 2 shows the received power P plotted as a function of the refractivity gradient ΔN, computed by subtracting the mean of N_s at the end points from the value of N at 5,000 ft over midpath. It shows a fairly close fit except for cases with trapping layers aloft. The relationship is not linear; its exact form is hard to assess.

Similar attempts to fit P to values of ΔN computed using N-values from 3,000 to 10,000 ft over the midpoint yielded much poorer results. The reason for this is not completely clear. Ray tracing by Anderson's [1958] graphical methods indicated that the base of the common volume varied from around 7,500 ft in some tropical air masses to as high as 12,000 ft in polar air masses. However, the *important* bending occurs in the first few hundred feet above ground at the ends of the path. Most of the refractivity versus height profiles given in Volume II of Latour's report can be approximated by straight lines up to a height of 5,000 to 10,000 ft. At higher elevations $|dN/dh|$ decreases so an entire curve can best be approximated by an exponential. Apparently averaging over 5,000 ft reduces the effects of measurement errors and small-scale variations in refractivity, while the gradient remains relatively constant. In going up to 10,000 ft one introduces a region with a gradient different from that at the surface, which distorts the results. In this connection, Latour reported that the change in refractivity from the surface to the 700-mb level ($\sim$10,000 ft) showed less correlation with received power than did the surface refractive index. This is in line with our findings. It should be noted, however, that this

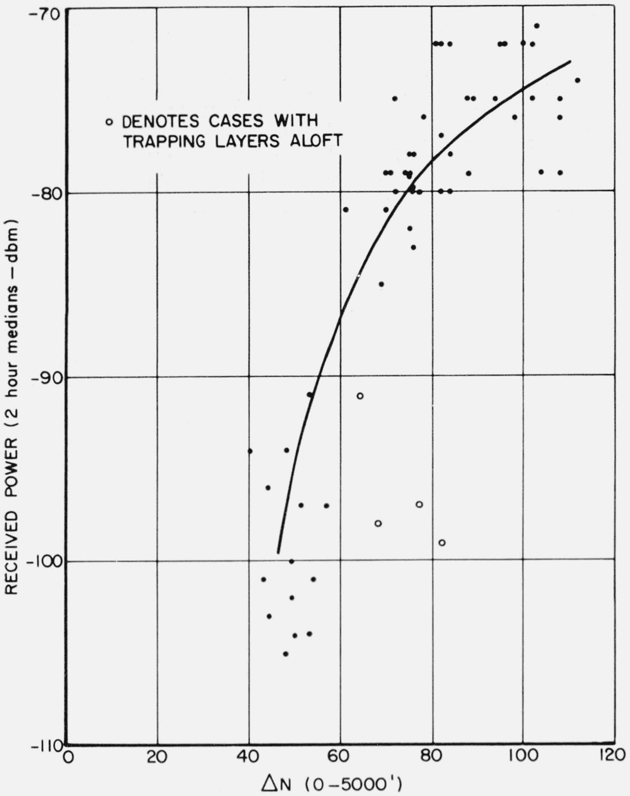

FIGURE 2. *Received power versus effective refractivity gradient (Cape Canaveral—New Providence Is.).*

result differs from Bean and Cahoon's [1961] finding. On all but one of the 21 paths which they studied, the correlation coefficient between L_B and ΔN is nearly the same whether ΔN is computed from the surface up to 1, 2, or 3 km.

As a check on the importance of the linearity of the relationship between refractivity and height, 34 cases with dN/dh nearly constant up to 5,000 ft were selected. For these k, the effective earth radius factor, was computed according to

$$k = \frac{1}{1+(10^{-6})a\cdot\frac{\Delta N}{\Delta h}} \tag{3}$$

where a is the actual radius of the earth [Schelleng, et al., 1933]. Log P was then plotted against log k and a curve fitted by eye. The other cases except for four with trapping layers aloft, i.e., layers with k negative, were then added to the scatter diagram. These did *not* increase the scatter about the fitted line to any noticeable degree, indicating that the linearity of the gradient is not essential to the correlation between ΔN and P. The result is shown as figure 3. The statistics for the 56 pairs are:

$\overline{P}$	=Mean received power	$=-82.8$ dbm
$S(P)$	=Standard deviation	$=$ 14.0 db
S_E	=RMS departure from fitted line	$=$ 4.2 db

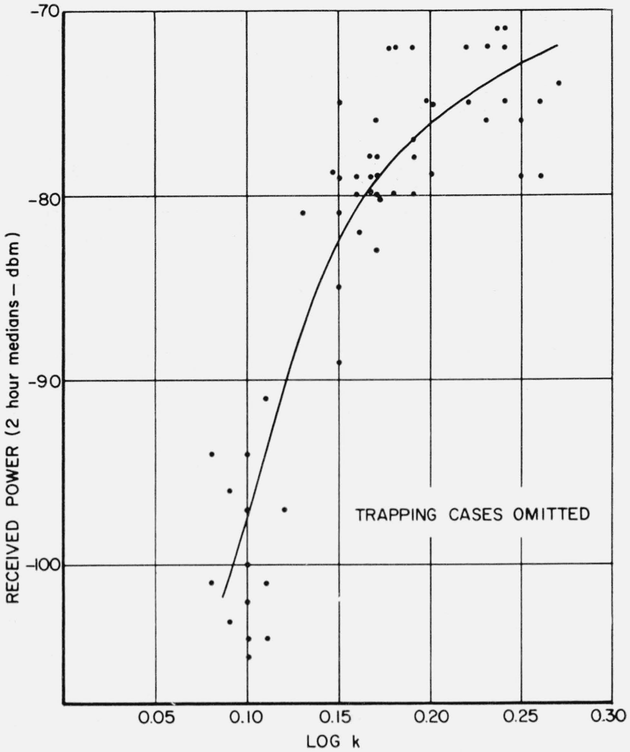

FIGURE 3. *Received power versus log* k *(Cape Canaveral—New Providence Is.).*

$$\text{Correlation Factor} = \left[1-\frac{S_E^2}{[S(P)]^2}\right]^{\frac{1}{2}} = 0.92$$

It is seen that *on this link* most of the variance in signal level can be correlated with the changes in refractivity gradient in the lower atmosphere without reference to stability parameters as introduced by Misme. This does not mean that conditions in the common volume are unimportant, but that the conditions there are themselves correlated with the refractivity gradient near the ground, and with the surface refractivity.

Attempts to improve the correlation factor by considering the moisture content of the common volume as an additional independent variable were not successful. In any case, measurement errors, which are of the order of 2 db, establish a lower limit to S_E. The rest of the residual variance can be attributed to small-scale weather systems, such as bands of cumulus clouds or showers, not detected by the coarse radiosonde network. At the wavelength used (24 cm) forward scatter by large raindrops could assume importance, as well as the refractivity gradients around individual clouds.

In the treatment in terms of effective earth radius we have ignored the four cases with trapping layers aloft. These occurred in polar air outbreaks with high barometric pressure; the trapping layers marked subsidence inversions in the high pressure areas. In these cases the received signals were generally between -90 and -100 dbm, with a tendency to fluctuate considerably.

3. Correlation of Scattered Signals and Refractivity Gradients: San Diego—Santa Ana

One of the cases analyzed by Bean and Meaney [1955] was an 85-mile link between Station KFSD in San Diego and a receiver at Santa Ana, near Los Angeles. This link offered a good opportunity to see if daily variations in signal level can be related to refractivity gradients in a climatic regime very different from Florida's and also to compare such results with those obtained from monthly medians. The Central Radio Propagation Laboratories of the National Bureau of Standards provided hourly median values of the basic transmission losses on the path and refractivity profiles computed from radiosonde data for Long Beach and San Diego. The months of May 1951, August and November 1952, and February 1953 have been analyzed.

As a first step, the hourly median basic transmission loss, L_B, was plotted against ΔN, with ΔN being computed from the surface to 1 km in this case to agree with the Bean and Meaney procedure. It was computed separately for Long Beach and San Diego and the average of the two results taken as the effective ΔN. For May 1951 only surface data were available for San Diego, and the 1-km values at Long Beach were assumed to apply. Transmission losses were measured during afternoon hours only, and all results are for 1900 PST, the time of radiosonde observations during the years in question. Some days were missing. A total of 100 measurements were used in the analysis.

Regression equations relating L_B to ΔN were obtained for the individual months and for the 100 cases combined. These equations and the one by Bean and Meaney derived from monthly medians are (r=correlation coefficients):

February	$L_B=182.7+0.45\ \Delta N,\ r=0.84$	(4)
May	$L_B=167.6+0.35\ \Delta N,\ r=0.73$	(5)
August	$L_B=173.4+0.39\ \Delta N,\ r=0.39$	(6)
November	$L_B=180.6+0.47\ \Delta N,\ r=0.75$	(7)
Combined	$L_B=178.0+0.44\ \Delta N,\ r=0.78$	(8)
Bean and Meaney	$L_B=181.3+0.48\ \Delta N,\ r=0.92$	(9)

Figure 4 shows the November data to illustrate the results obtained by comparing individual hourly medians with ΔN. The two approaches lead to essentially the same results, as a comparison of (8) and (9) shows. That the correlation coefficient is smaller when the regression equation is computed from individual cases rather than from monthly medians appears to be due to the fact that averaging smooths out measurement errors [Bean, 1956]. However, it should be recognized that the computed correlation coefficients are only estimates of the true correlation between the variables in question. A different November, say, might yield a value of r considerably different from that found for (7).

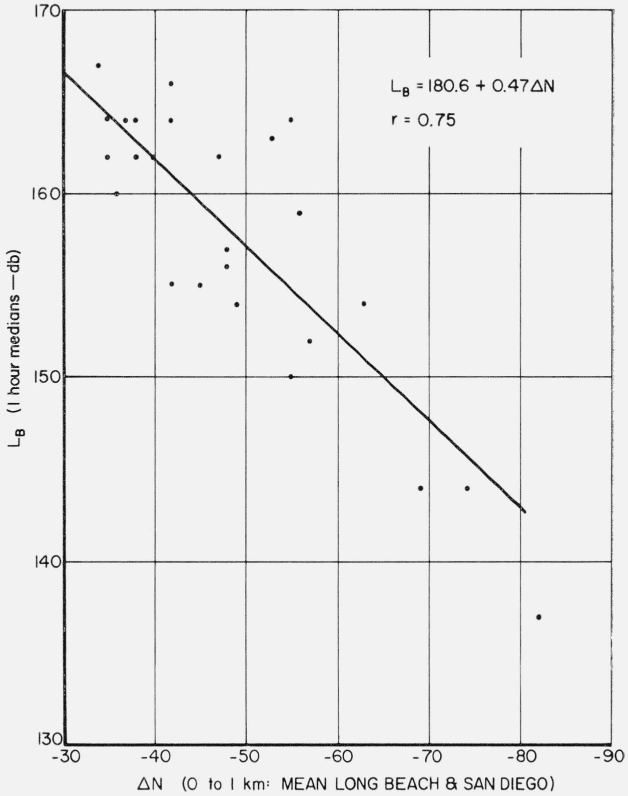

FIGURE 4. *Basic transmission loss versus refractivity gradient (San Diego—Santa Ana, November 1952).*

The standard error of estimate about each regression line is given to a first approximation by

$$S_E=S(L_B)[1-r^2]^{\frac{1}{2}}, \tag{10}$$

where $S(L_B)$ is the standard deviation of L_B for the sample involved. Bean and Meaney found $S(L_B)$ for the monthly medians to be 6.7 db, and so the standard error for (9) is near 2.7 db. The standard deviation for the 100 individual hourly medians which we have studied is 9.9 db, and so the standard error for (8) is 6.2 db. However, if we were to apply (8) to each case for a month and then combine the results to get the *monthly* median, the error in the monthly median would be considerably less than 6.2 db.

The pronounced drop in the correlation coefficient r in August is likely due to the frequent inversions experienced along the Southern California coast in summer. Bean and Cahoon [1961] found that the correlation between monthly medians of L_B and ΔN on this link was negative if ΔN was measured from the surface to some height below the base of the inversion, around 500 to 600 m, but positive if ΔN included the drop in N at the inversion. This result suggests that the propagation over this link in inversion situations is by partial reflections at the inversion layer. Strong inversions on the California coast are ordinarily accompanied by weak refractivity gradients in the marine layer underneath; this could account for the negative correlation between L_B and the initial refractivity gradient. Evidence for such a propagation mechanism is provided by beam-swinging experiments conducted in the same area by Ortwein et al. [1961]. In any event, the correlation between L_B and ΔN (to 1 km), computed on a daily basis, is so low for August that ΔN provides little information about the day-to-day variations in L_B during that month.

4. Conclusions

Significant correlations between individual hourly median troposcatter signals and refractivity gradients near the surface as measured by radiosondes can be derived on at least some links over water and in coastal areas. For these cases, short-term predictions of circuit performance can be derived from meteorological parameters (pressure, temperature, and humidity) ordinarily used in preparing weather forecasts for other purposes.

Attempts to derive similar simple relationships for an inland link have not proved as successful to date. Additional observational programs involving meteorological as well as electronic instrumentation would be helpful in deriving relationships between radio field strengths and weather conditions applicable in different climatic regimes and over different types of terrain.

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