2. DISCUSSION OF METEOROLOGICAL EFFECTS

2.1 Refractivity Gradients

General information on refractivity gradients and their measurement is available in a number of publications; e.g., Burrows and Attwood (1949), Bean et al. (1966), Bean and Dutton (1968), Hart et al. (1971), and Samson (1975a, b). Refractivity gradients are influenced by the local topography, ground cover, moisture sources, and synoptic weather conditions, none of which are exactly the same at two stations. Refractivity statistics are also affected by the time of observation.

In the utilization of the refractivity gradient distributions it should be noted that the graphs do not show the total percentage of time in a year, but only the percentage of occurrence at the time of the brief daily observations in the lowest 100-m layer. In other words, the percentage read from one of the graphs for a specific value of the gradient is the percentage of the observations in which this gradient was exceeded (or not exceeded) in the lowest 100-m layer. Since the radiosonde package rises through this 100-m layer in less than 30 sec, and most stations take only two radiosonde observations a day, the total annual sampling time amounts to about six hours. It is difficult to determine the statistical significance of these data; the time interval over which a single observation might be expected to be representative will vary with the local climatic conditions as well as the time of observation. Refractivity changes with time are usually small around mid-day, but may be large in the periods near sunrise and sunset. Because of the influence of the heating and cooling of the earth's surface on the stratification of air layers near the ground, local refractivity gradients are closely related to the local or sun-referenced time, and extreme gradients often develop near sunrise and sunset, when the thermal structure of the air near the ground is changing rapidly. Consequently, observations made during these periods may not be representative of the conditions existing even one hour earlier or later.

Since most radiosonde stations, by international agreement, take observations at 12-hr intervals based on Greenwich time (0000Z and 1200Z at present), the local times of observation vary with station longitude. For example, a station at 60° east longitude takes the 0000Z observation at 0400 local time, while a station at 120° east longitude takes it at 0800 local time. At latitude 40°N in early June, one station would be taking an observation about 30 min before sunrise, and the other station's observation would be about 3 1/2 hours after sunrise. Although the two stations might have similar climates, sizeable differences in the RAOB-derived refractivity statistics would be likely because of the difference in the local time of observation, and suitable allowances should be made when comparing the data for these stations.

The application of the refractivity statistics to system design problems requires consideration of the following:

a. Length of observational record (i.e., is it likely to be a representative sample?)

b. Local time of observation (i.e., were data taken at times likely to have sampled both normal and extreme gradients?)

c. Station location and relative local climate (e.g., a radio link between two high mountains may have a much different "path climate" than would be indicated by climatological records from a weather station in a nearby river valley, and a radio system closely following an ocean coastline may be affected by conditions not reflected in the observations at weather stations only 20 or 30 km inland).

Coastal locations may have extreme refractivity gradients develop because of temperature and humidity contrasts related to the ebb and flow of marine and continental air masses* involved in land-sea breeze circulations, and the lower atmosphere in larger river valleys is frequently stratified by air drainage.

2.11 Seasonal Effects

Seasonal changes in the gradient distribution are small at many island stations (e.g., see data for Raoul, Stanley, and Ascension). Nandi, in the Fiji Islands, shows more seasonal change, and a large amount of subrefraction, but this station is on a very large island (10386 km^2) with a land surface large enough to have a local modifying influence on the prevailing marine air.

Continental stations are subject to large seasonal changes in air masses, from cold and dry in winter to hot and humid (at times) in summer. For example, Rantoul and Bismarck have considerably more superrefraction in May and August than in February and November, while Edmonton has much more superrefraction in August than in the other months. These seasonal differences can be attributed mainly to the greater water vapor content of summer air masses, which makes possible more intense refractivity contrasts. Table 1 shows the average surface dewpoint temperature, which is a convenient measure of water vapor content, at these stations in the four months representing the seasons.

Table 1. Mean Surface Dewpoint Temperature in °F.

	Feb.	May	August	November
Edmonton	8	35	50	18
Bismarck	8	39	53	19
Rantoul	25	50	63	31
Burrwood	45	66	74	53

In contrast to the other stations, Burrwood (on the Gulf of Mexico) has relatively moist air at lower levels in all months of the year, and much higher incidence of superrefraction in February than the inland stations. In the

*An air mass is a large body of air whose temperature and moisture characteristics are approximately homogeneous, and reflect to some degree the characteristics of the source region.

warmer months, when Gulf air masses frequently reach the Rantoul area, the refractivity distributions at Rantoul and Burrwood show similar amounts of superrefraction.

Seasonal changes in air mass and refractivity characteristics also occur in areas subject to monsoon circulations (i.e., seasonal shifts in the direction of the prevailing winds). For example, in southeast Asia the shift from the showery southwest monsoon to the northeast monsoon tends to increase the probability of superrefraction and ducting gradients, as the drier air moves over generally moist or wet land areas. This is reflected in the November and February distributions for Bangkok.

Under conditions of very low humidity at all levels in the lower atmosphere, ducting is still possible if temperature inversions are very large. At Amundsen-Scott there is very little ducting during November and February, when the sun is above the horizon. The sun is below the horizon at this station from about March 23 to September 21, and temperature inversions of 10° to 25° C develop because of radiation from the snow-covered surface in the long Antarctic night (Bean et al., 1966). This results in ducting gradients in the lowest 100-m layer about 50% of the time in May and August.

2.12 Diurnal Effects

The refractivity gradient near the surface changes as the temperature and humidity profiles change. The usual diurnal temperature variation, from maximum in the afternoon to minimum near sunrise, affects the refractivity gradient, as well as changes in humidity related to condensation and evaporation. In some areas there is also a diurnal shift in wind direction, as in land- and sea-breeze circulations or mountain and valley winds, that can affect the refractivity structure. Convection, or the large-scale vertical motion of air resulting from surface heating, is also a factor, since it will tend to mix the air, which usually results in reduced intensity of the refractivity gradients. These regular diurnal effects are superimposed on the synoptic-scale changes in air mass characteristics resulting from moving pressure systems, monsoonal changes in circulation, and local modification of air masses caused by changes in growing crops or wide-scale irrigation.

The diurnal variation in the refractivity structure tends to be closely related to the diurnal temperature variation. At the time of minimum temperature, when the surface inversion is fully developed, humidity contrasts between layers are often high, and large negative gradients frequently develop (although subrefraction is also possible). At the time of maximum surface temperature, convection and vertical mixing are at a peak, and the refractivity gradients tend toward the "normal" value of -40 to -50 N-units/km, although under some conditions subrefractive or positive gradients may develop in the afternoon (e.g., see Las Vegas for May and August). Because the standard two daily observations are unlikely to coincide with these positive and negative gradient peaks, or limits of the gradient variation, most data from the regular radiosonde networks will probably indicate less diurnal variation in the low-level refractivity gradients than actually occurs.

The observations available for this study were not uniformly distributed throughout the day (in local time) because the geographical coverage was not uniform. In the group of stations for which separate distributions were prepared for each time of observation, observations were predominantly in the 0700 to 1000 LST and 1900 to 2200 LST time periods. However, certain general tendencies are evident when the data are grouped in large time blocks.

For a group of 21 continental and coastal stations, subrefraction, superrefraction, and ducting occurred more frequently from 2000 LST to 0700 LST than from 0800 LST to 1900 LST, and the part of the day with fewest abnormal gradients was from 1200 to 1500 LST. In contrast, data from two island stations in the Pacific (Guam and Lihue) indicate that superrefraction and ducting occurred more often at 1300 and 1600 LST than at 0100 and 0400 LST.

Data were available for four stations that made observations four times a day, at 6-hr intervals. These stations were Dayton, Mt. Clemens, and Rantoul in the U.S., and Lajes in the Azores. The first three stations (observations at 0300, 0900, 1500, and 2100 LST) are in a continental climate area, but Lajes (observations at 0400, 1000, 1600, and 2200 LST) is on an island in the Atlantic with a maritime exposure. At Rantoul and Mt. Clemens, subrefraction occurred most frequently on the 0300 LST observation; at Dayton the highest incidence was at 2100 LST. At Lajes, subrefraction was primarily a nighttime phenomenon, except in August when the greatest frequency of occurrence was in the daytime. In general, there was more superrefraction and ducting at night (0300 and 2100 LST) than in the daytime (0900 and 1500 LST) at the U.S. stations, but at Lajes there were more superrefractive gradients in the daytime (1000 and 1600 LST) than at night in May and August.

The tendency for daytime superrefractive conditions at Lajes is similar to what is observed at Guam and Lihue. At all three stations the primary cause is probably a rapid decrease in humidity with height, rather than a temperature inversion. The air reaching these stations has had a long over-water trajectory, and over the oceans the water vapor content of the air near the surface is near saturation at all times. The diurnal temperature range is small, with the maximum in the lower few meters occurring about two hours after local noon and the minimum shortly before dawn (Deacon, 1969). The air near the sea surface would thus have a slightly greater capacity for water vapor in the daytime than at night, and the moisture lapse would tend to be greatest in the daytime.

The Las Vegas data for May and August illustrate the type A subrefraction (Hart et al., 1971) caused by extreme surface heating with relatively dry air. There is a high occurrence of subrefraction at 1600 LST, which is near the time of maximum temperature (the average daily maximum at Las Vegas is 88° F in May and 101° F in August). On the other hand, superrefraction occurs more frequently at 0400 LST in all seasons.

The indicated diurnal variability for the stations in Argentina is relatively small; however, note that these data are presented as all-season or annual distributions, which tends to mask the extent of the diurnal and seasonal variations. Also, all but one of these analyses were based on observations at 0800 and 2000 LST, which may not be optimum for sampling of gradient extremes.

2.2 Rainfall Rates

The attenuation of microwave energy by precipitation varies with frequency, and is affected by temperature, drop size and shape, terminal velocity of the drops, and the total water volume. For practical purposes, attenuation has usually been related only to the instantaneous rainfall rate (Medhurst, 1965). The data upon which the distributions in appendix B are based are point rates averaged over 1 to 5 minutes, which can be assumed to represent "instantaneous" rates for most engineering applications. Rain gages do not measure storm rainfall, rather, they sample the rainfall as the storm moves over the gage, and the sampling errors may be large. The sample obtained in any particular storm is not likely to reflect the highest rates in that storm, since the gage orifice covers such a small area and the intensity of precipitation varies throughout the storm at any instant and is also varying with time as the storm develops and decays (Samson, 1975b).

Estimating the effect of rainfall on a particular radio link involves more than an evaluation of climatological values of point rainfall rate and the attenuation per unit distance. The average rate of rainfall within a storm cell and the spatial extent of the storms will affect the total path attenuation, and the character of the storm situation is also very important, i.e., whether or not the storms are likely to be scattered through the area, or a part of a frontal system or squall line (Barsis and Samson, 1976).

The comparison of the rainfall rate distributions for Seattle and Urbana in figure 1 illustrates the need for considering the character of precipitation in estimates for radio link design. For some applications it is also useful to consider the average time of day in which precipitation occurs, the direction of movement of storms, and the effects of terrain.

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