4. DETERMINATION OF AN EFFECTIVE EARTH'S RADIUS

The bending of a radio ray as it passes through the atmosphere is largely determined by the gradient of the refractive index near the earth's surface. In order to represent radio rays as straight lines, at least within the first kilometer above the surface, an "effective earth's radius" is defined as a function of the refractivity gradient, ΔN, or of the surface refractivity value N_s,

$$N_s = (n_s - 1) \times 10^6 \tag{4.1}$$

where n_s is the atmospheric refractive index at the surface of the earth.

In the United States the following empirical relationship has been established between the mean N_s and the mean refractivity gradient ΔN in the first kilometer above the surface:

$$\Delta N/\text{km} = -7.32 \exp(0.005577\, N_s). \tag{4.2}$$

Similar values have been established in West Germany and in the United Kingdom [CCIR 1963e].

In this paper values of N_s are used to characterize average atmospheric conditions during periods of minimum field strength. In the northern temperate zone, field strengths and values of N_s reach minimum values during winter afternoons. Throughout the world, regional changes in expected values of transmission loss depend on minimum monthly mean values of a related quantity, N_o, which represents surface refractivity reduced to sea level:

$$N_s = N_o \exp(-0.1057\, h_s) \tag{4.3}$$

where h_s is the elevation of the surface above mean sea level, in kilometers, and the refractivity N_o is read from the map shown in figure 4.1 and taken from Bean, Horn, and Ozanich [1960].

Most of the refraction of a radio ray takes place at low elevations, so it is appropriate to determine N_o and h_s for locations corresponding to the lowest elevation of the radio rays most important to the geometry of a propagation path. As a practical matter for within-the-horizon paths, h_s is defined as the ground elevation immediately below the lower antenna terminal, and N_o is determined at the same location. For beyond-the-horizon paths, h_s and N_o are determined at the radio horizons along the great circle path between the antennas, and N_s is the average of the two values calculated from (4.3). An exception to this latter rule occurs if an antenna is more than 150 meters below its radio horizon; in such a case, h_s and N_o should be determined at the antenna location.

The effective earth's radius, a, is given by the following expression:

$$a = a_o [1 - 0.04665 \exp(0.005577\, N_s)]^{-1} \tag{4.4}$$

where a_o is the actual radius of the earth, and is taken to be 6370 kilometers. Figure 4.2 shows the effective earth's radius, a, plotted versus N_s. The total bending of a radio ray which is elevated more than 0.785 radians (45°) above the horizon and which passes all the way through the earth's atmosphere is less than half a milliradian. For studies of earth-satellite communication ray bending is important at low angles. At higher angles it may often be neglected and the actual earth's radius is then used in geometrical calculations.

Large values of ΔN and N_s are often associated with atmospheric ducting, which is usually important for part of the time over most paths, especially in maritime climates. The average occurrence of strong layer reflections, superrefraction, ducting, and other focusing and defocusing effects of the atmosphere is taken into account in the empirical time variability functions to be discussed in section 10. Additional material on ducting will be found in papers by Anderson and Gossard [1953a, b], Bean [1959], Booker [1946], Booker and Walkinshaw [1946], Clemow and Bruce-Clayton [1963], Dutton [1961], Fok, Vainshtein, and Belkina [1958], Friend [1945], Hay and Unwin [1952], Ikegami [1959], Kitchen, Joy, and Richards [1958], Nomura and Takaku [1955], Onoe and Nishikori [1957], Pekeris [1947], Schünemann [1957], and Unwin [1953].

MINIMUM MONTHLY SURFACE REFRACTIVITY VALUES REFERRED TO MEAN SEA LEVEL

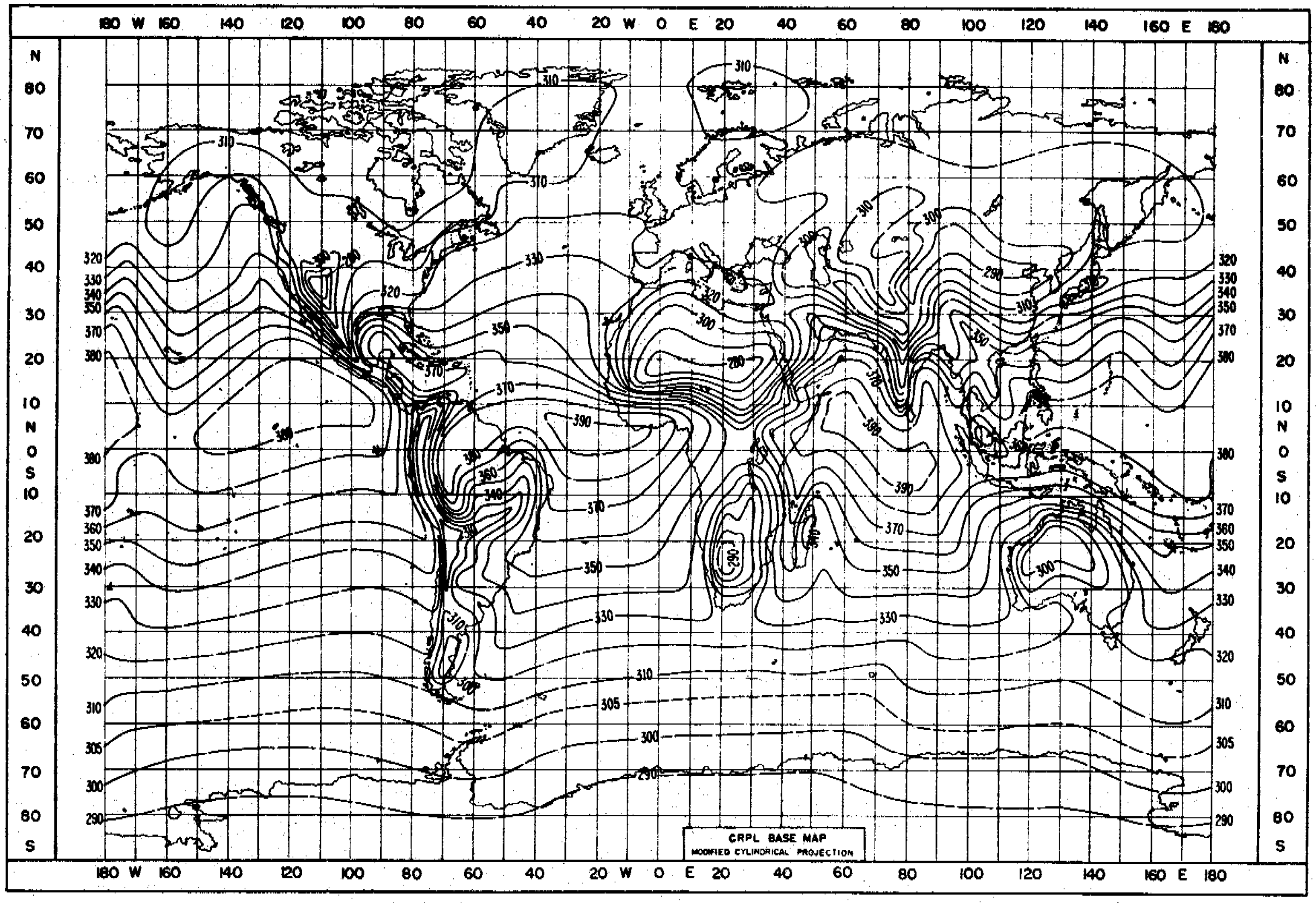

Figure 4.1

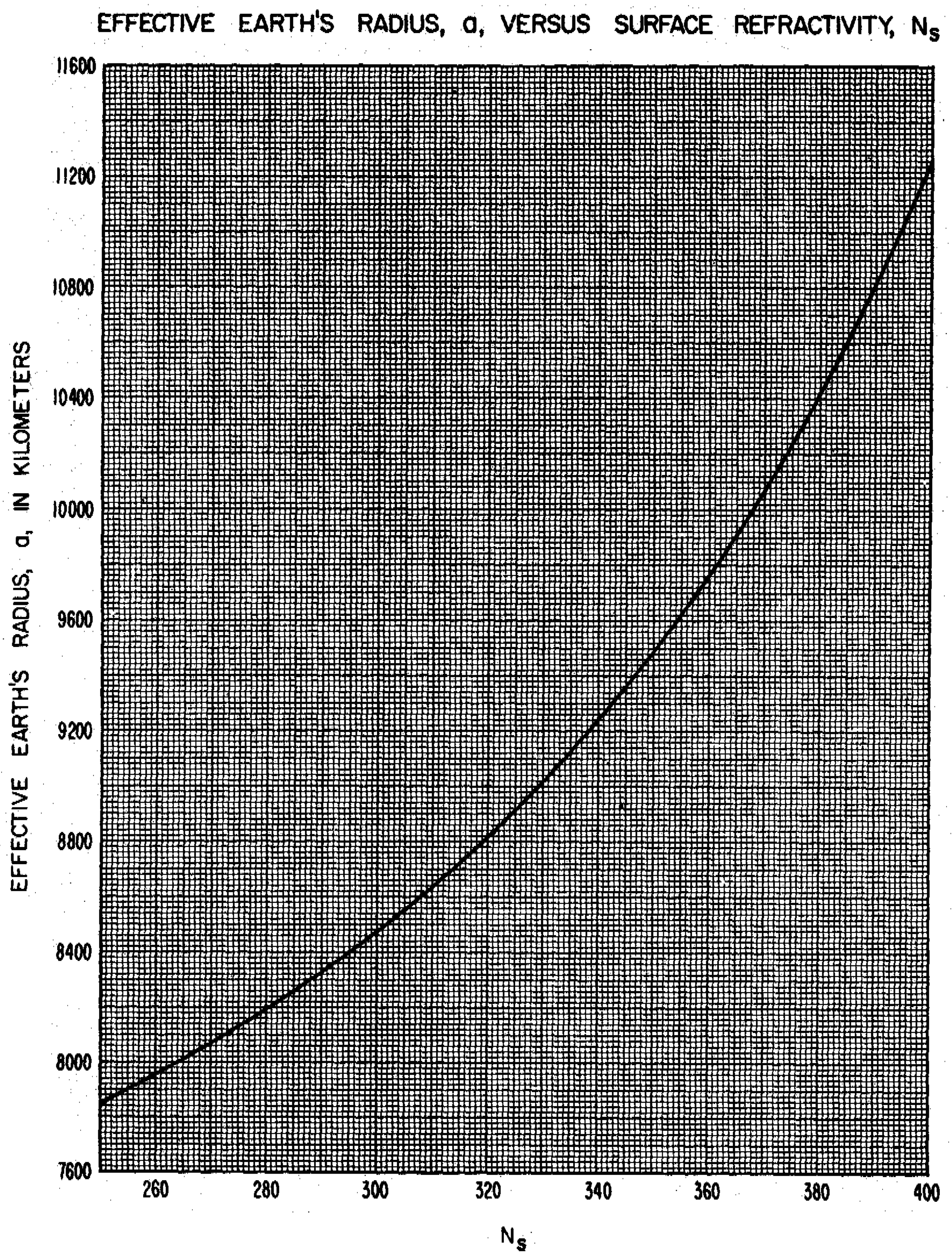
EFFECTIVE EARTH'S RADIUS, a, VERSUS SURFACE REFRACTIVITY, N_s
EFFECTIVE EARTH'S RADIUS, a, IN KILOMETERS
11600
11200
10800
10400
10000
9600
9200
8800
8400
8000
7600
260
280
300
320
340
360
380
400
N_s

Figure 4.2