INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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" SPRING COLLEGE ON GEOMAGNETISM AND AERONOMY "

(2 - 27 March 1987)

Appendix to the lectures

presented by :

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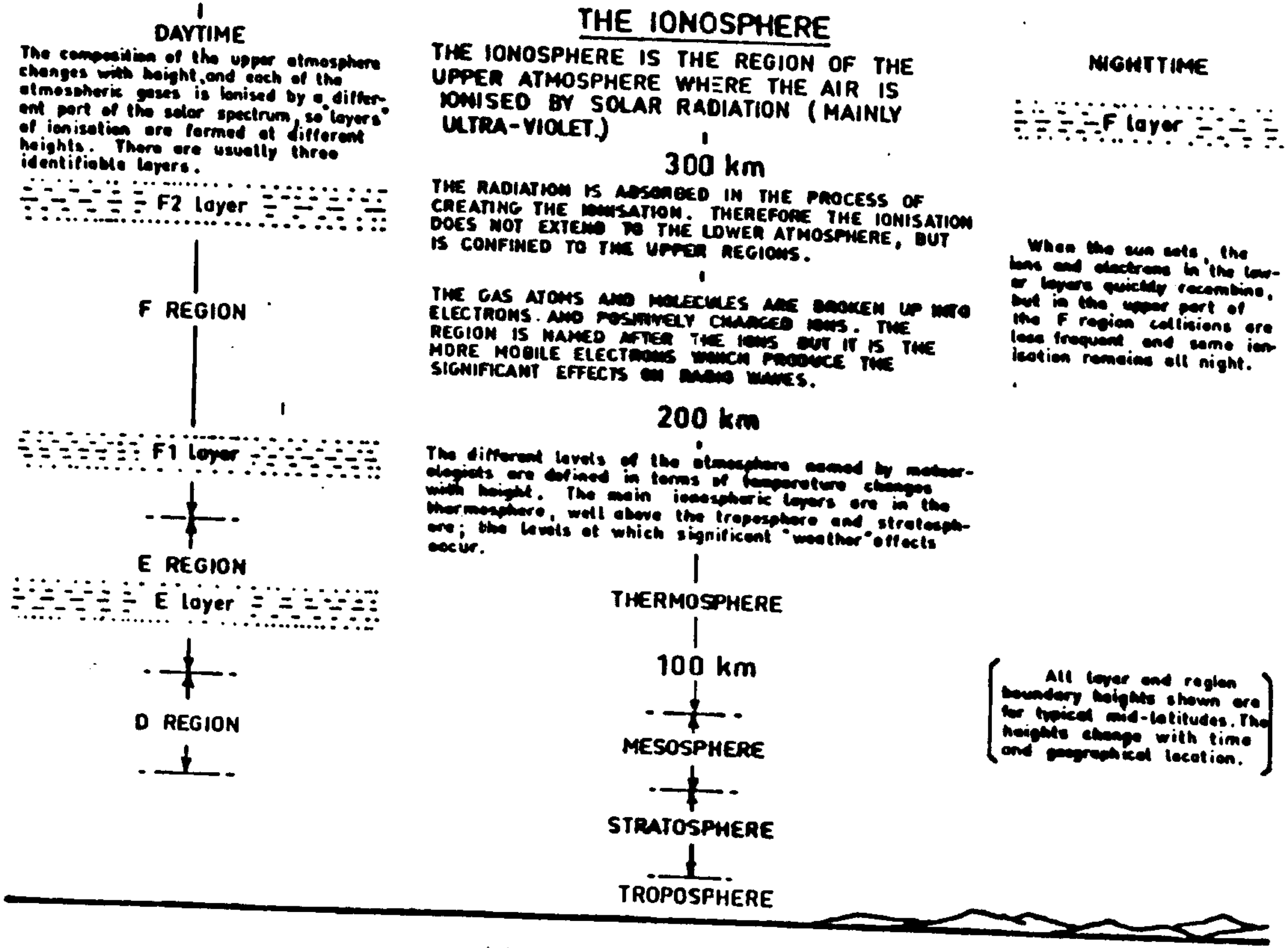
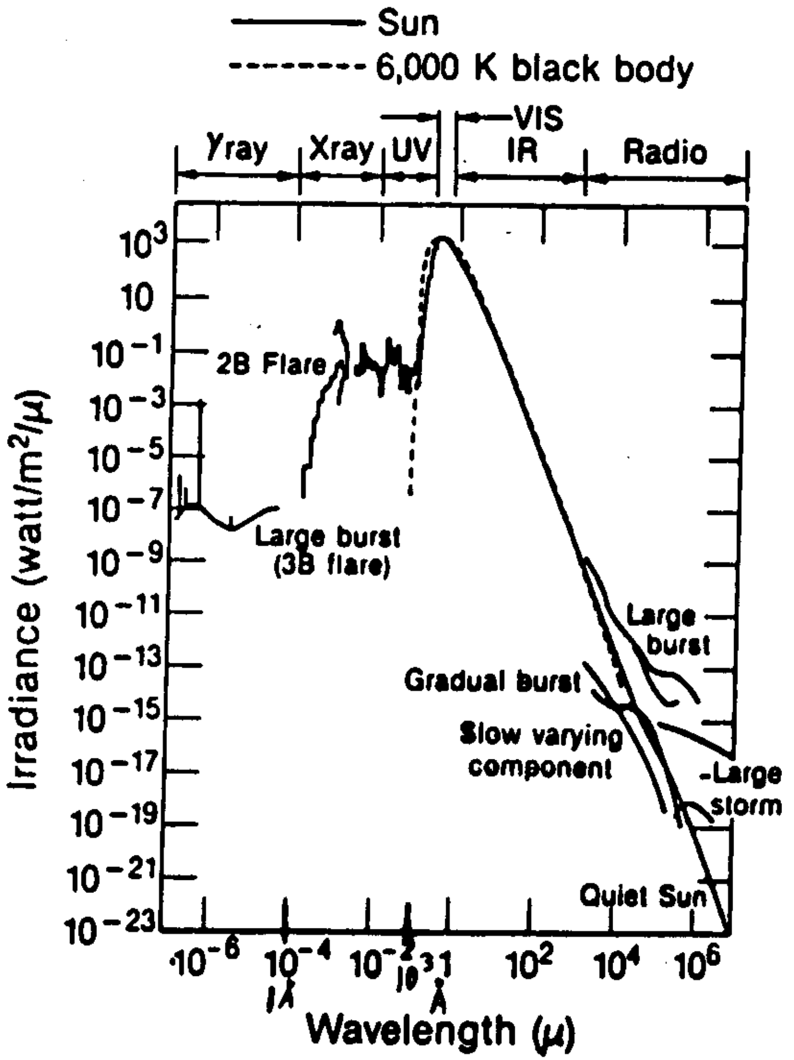


(from Australian IPS, 1982)

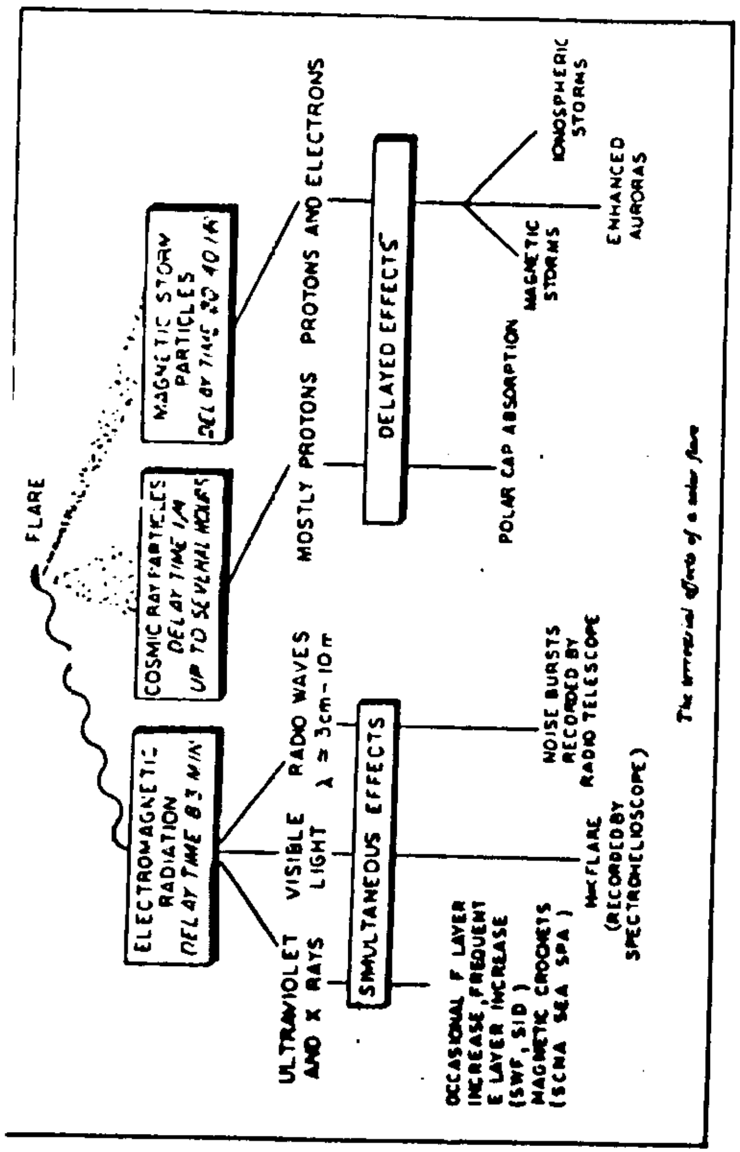


2. The spectrum of solar radiation (solid line), compared with it of a blackbody at 6000°K (dashed line), from *Nicolson* [1982].

$\simeq$ 100 - 900 Å (304 Å) O^+

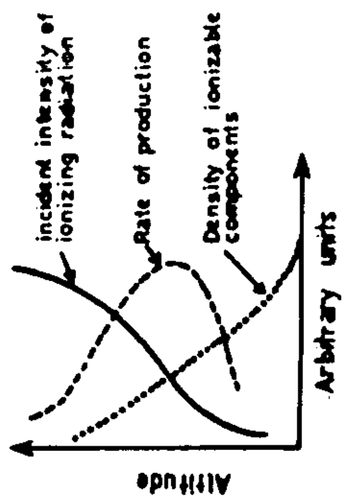
$\approx$ 10 - 100 Å, 800 - 1026 Å (O_2^+, NO^+)

$\approx$ 1 - 10 Å N_2^+, NO^+, O_2^+, O_2^-



(from Australian IPS, 1982)

A layer of electrons is produced when the sun's radiation falls on the neutral atmosphere and ionizes part of it. Different constituents of the atmosphere absorb ionizing radiation of different wavelengths and form the various layers of the ionosphere.



PRODUCTION OF IONIZATION

E & F1 REGIONS

$\left.\begin{array}{l} NO^+ \\ O_2^+ \end{array}\right\}$ MAJOR IONS

RECOMBINATION:

$O_2^+ + e \rightarrow O + O$ DISSOCIATIVE RECOMBINATION

$O_2^+ + e \rightarrow O_2 + h\nu$ RADIATIVE RECOMBINATION

$Loss = \alpha [X^+] Ne$, since $Ne = N[X^+]$

$q = L = \alpha Ne^2$

$N = N_m \exp \frac{1}{2}\left[1 - z - \exp(-z)\right]$, $z = \frac{h - h_m}{H}$

KNOWN AS AN α CHAPMAN LAYER.

F2 REGION

O^+ (MAJOR ION)

EFFECTIVE ATTACHMENT:

$O^+ + N_2 \xrightarrow{K1} NO^+ + N$ (ION-ATOM INTERCHANGE) $K1 \approx 10^{-12}$

$NO^+ + e \xrightarrow{K2} N + O$ (DISSOCIATIVE RECOMBINATION) $K2 \approx 10^{-7}$

$\text{EFF. } \beta \propto [N_2]$

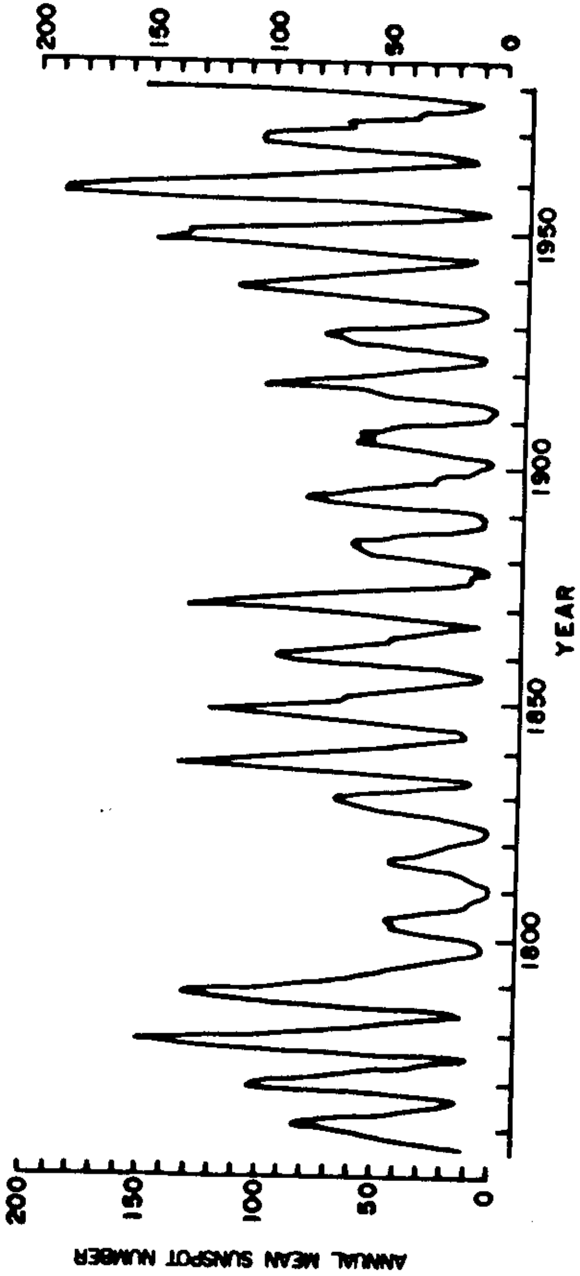
$q = L = \beta N_e$

$N = N_m \exp\left[1 - z - \exp(-z)\right]$

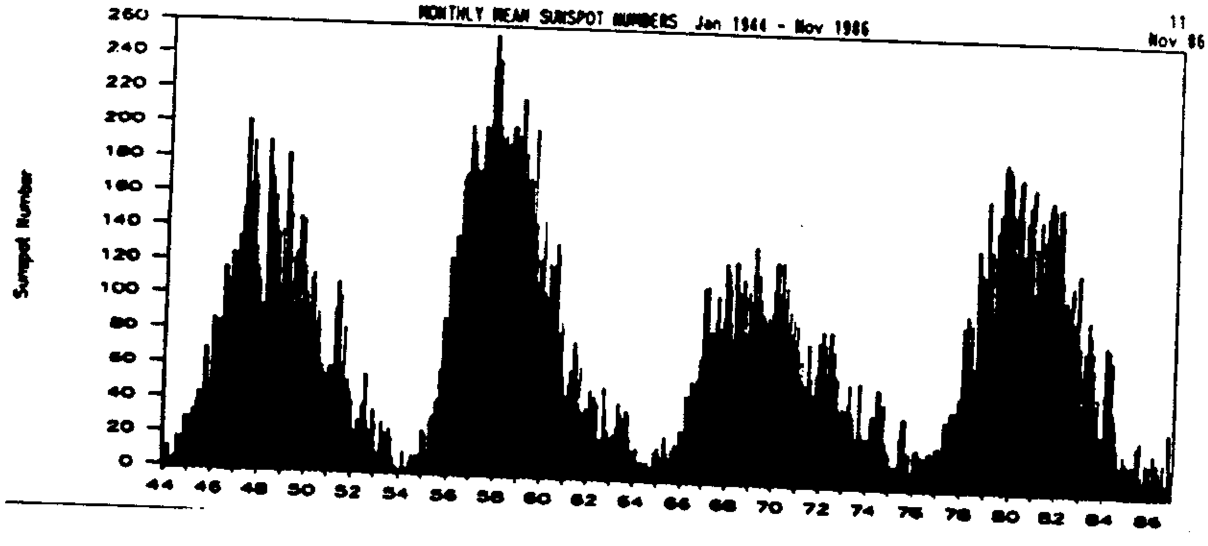
Table 10

Constituent	λ(Å)	IP (eV)	
NO	1340	9.25	E & F1
NH_3	1221	10.15	
C	1100	11.3	
O_2	1026	12.1	E & F1
H_2O	985	12.60	
CH_4	954	13.00	
H	912	13.59	
O	911	13.61	F2
CO_2	899	13.79	
CO	885	14.0	
H_2	804	15.41	F2
N_2	796	15.58	
A	787	15.75	
Ne	575	21.56	
He	504	24.58	F2

(from S.J. Bauer, private communication)



MEAN YEARLY SUNSPOT NUMBERS SINCE 1749



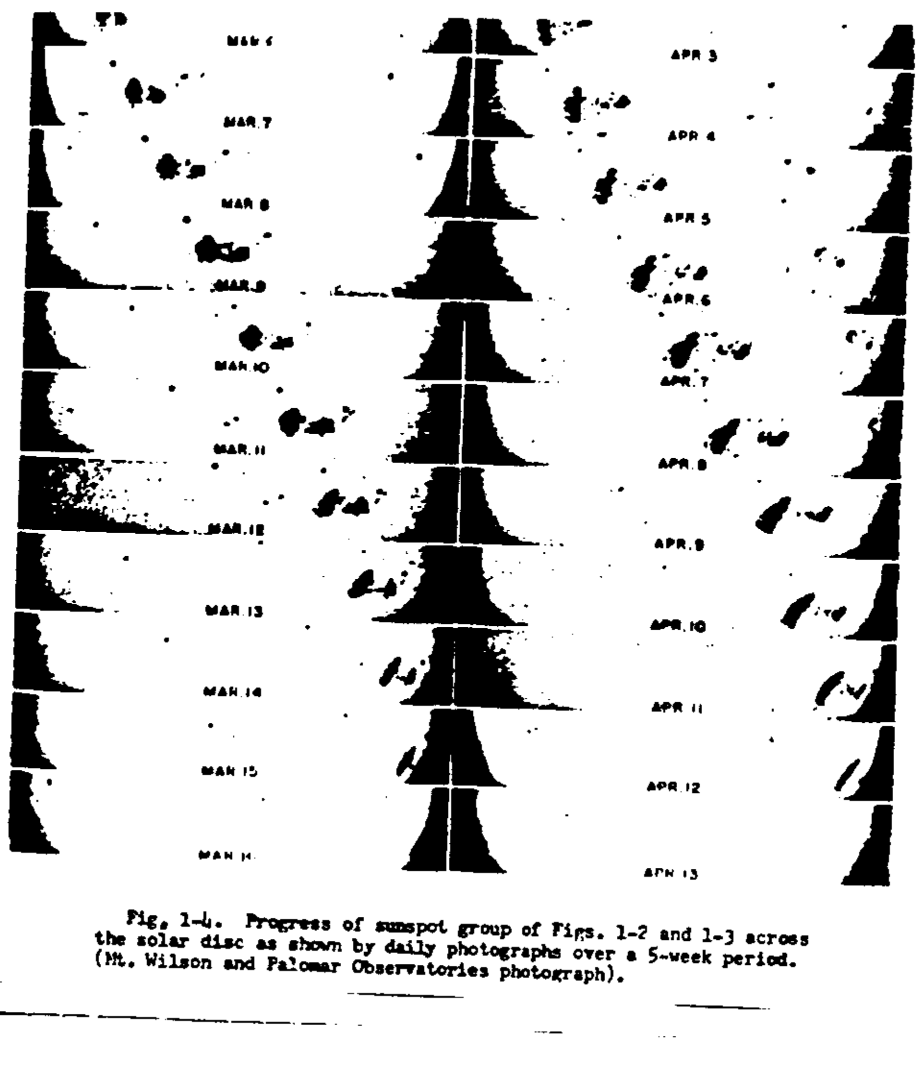


Fig. 1-4. Progress of sunspot group of Figs. 1-2 and 1-3 across the solar disc as shown by daily photographs over a 5-week period. (Mt. Wilson and Palomar Observatories photograph).

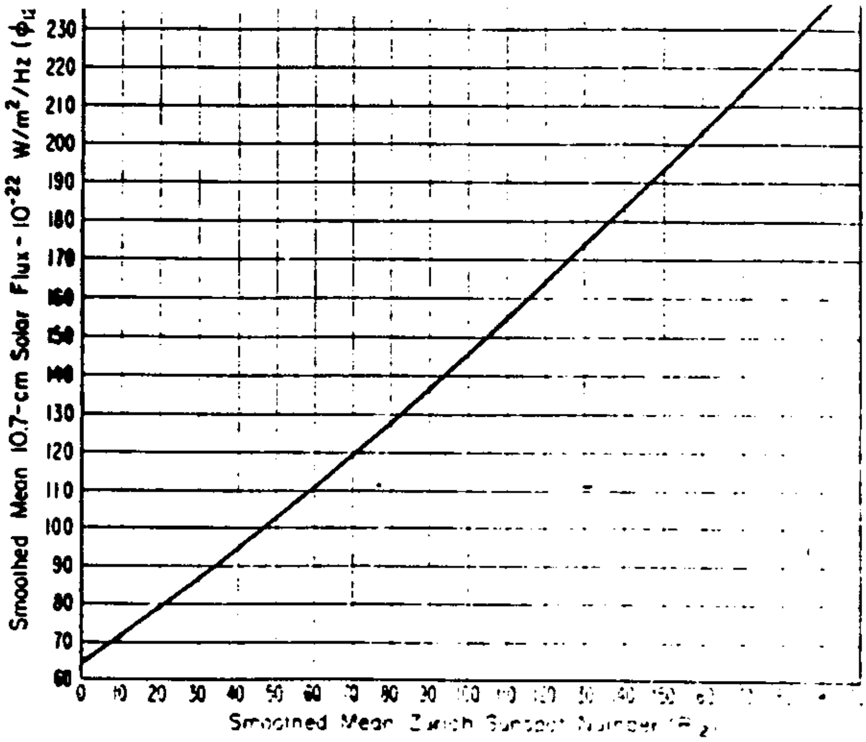


FIG 2 RELATIONSHIP BETWEEN SMOOTHED MEAN ZURICH SUNSPOT NUMBER AND SMOOTHED MEAN 10.7-cm SOLAR FLUX

$SSN = \sqrt{K1 + K2 * FLUX} - K3$ (from ITS-OT/TRER 13, Sept. 1971)

$K1 = 93{,}918.4$; $K2 = 1{,}117.3$; $K3 = 406.37$

OR: $FLUX = 63.7 + 0.728 * SSN + 8.95\times10^{-4} * SSN^2$

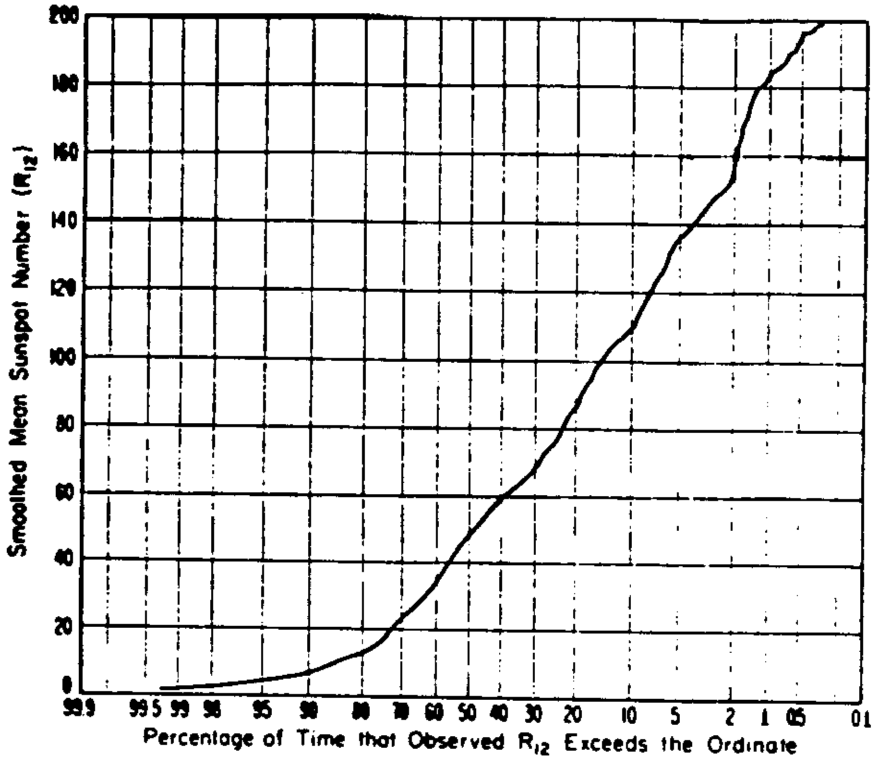


FIG. 1 CUMULATIVE DISTRIBUTION OF SMOOTHED MEAN ZURICH SUNSPOT NUMBERS, 1834 - 1969

(from ITS-OT/TRER 13, Sept. 1971)

APPLETON - HARTREE FORMULA FOR REFRACTIVE INDEX:

$$n^2 = 1 - \frac{X}{1 - jZ - \frac{Y_T^2}{2(1-X-jZ)} \pm \sqrt{\frac{Y_T^4}{4(1-X-jZ)^2} + Y_L^2}}$$

If $jZ \ll 1$ and neglecting the magnetic field, i.e. $Y_L = Y_T = 0$.

$$n^2 = 1 - X$$

If we just neglect collisions, we have:

$$n^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y_T^2 \pm \sqrt{Y_T^4 + 4(1-X)^2 Y_L^2}}$$

FOR $n = 0$; $X = 1$ or $X = 1 \pm Y$ .... } reflection ht.

If we put $\theta = 90°$ $\quad n^2 = 1 - X$ (+ sign) $\rightarrow X = 1$

or $n^2 = 1 - \frac{X(1-X)}{1-X-Y^2}$ (− sign) $\rightarrow X = 1 \pm Y$

ELECTRON GYROFREQUENCY, f_H :

$$f_H = \frac{|e|}{2\pi m} B = 28 * B_0 \quad (B_0 \text{ in } \gamma \text{ (nT)})$$

e.g. for $B_0 = 50{,}000\,\gamma$, $f_H = 1.4$ MHz.

PLASMA FREQUENCY, f_N :

$$f_N^2 = \frac{e^2 N}{\epsilon_0 m 4\pi^2}$$

$$f_N^2 = 80.5 N \qquad f \text{ in MHz}$$

N in el/m^3

e.g. $f \approx 9\sqrt{N}$, for $N = 1 \times 10^{12}$ el/m^3,

$f = 9 \times 10^6 = 9$ MHz.

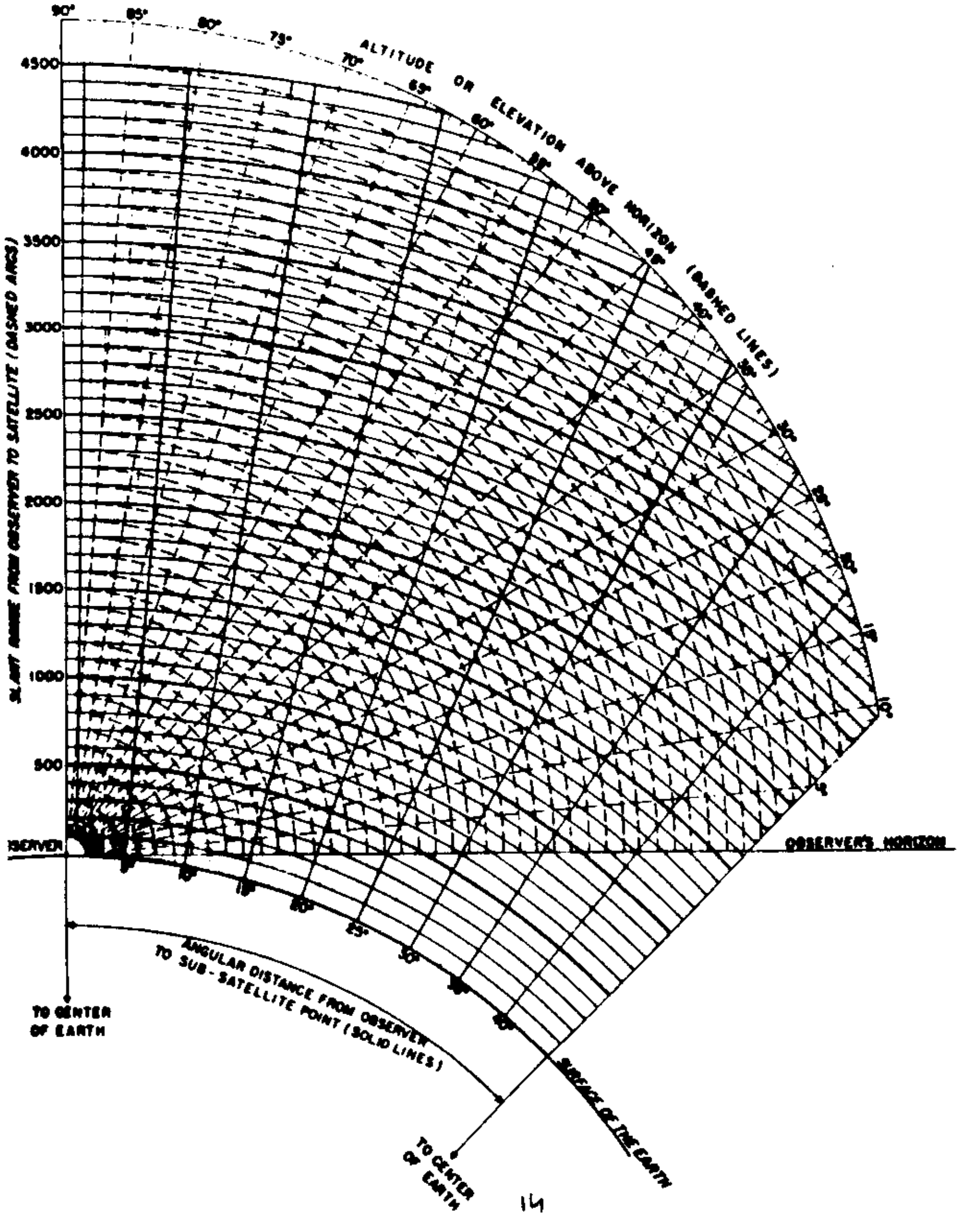
DEFINE:

$$X = \left(\frac{f_N}{f}\right)^2, \quad Y = \frac{f_H}{f}, \quad Z = \frac{\nu}{2\pi f}.$$

$Y_T = Y \sin\theta$, $Y_L = Y \cos\theta$, θ is the angle between the ray path and the earth's magnetic field.

CHART FOR DETERMINING ELEVATION & SLANT RANGE OF SATELLITE

ALL DISTANCES ARE IN STATUTE MILES — 5 STATUTE MILES EQUAL APPROXIMATELY 8 KILOMETERS



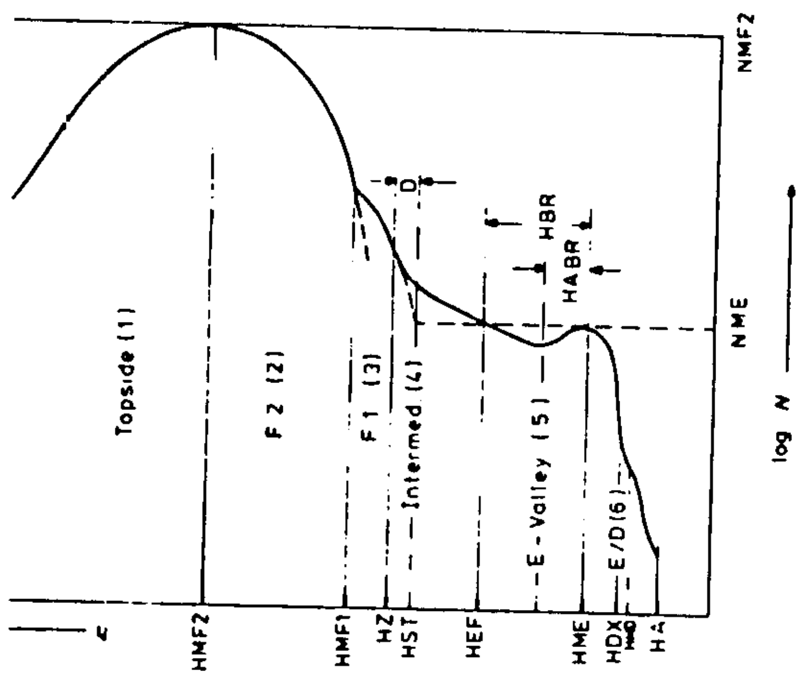
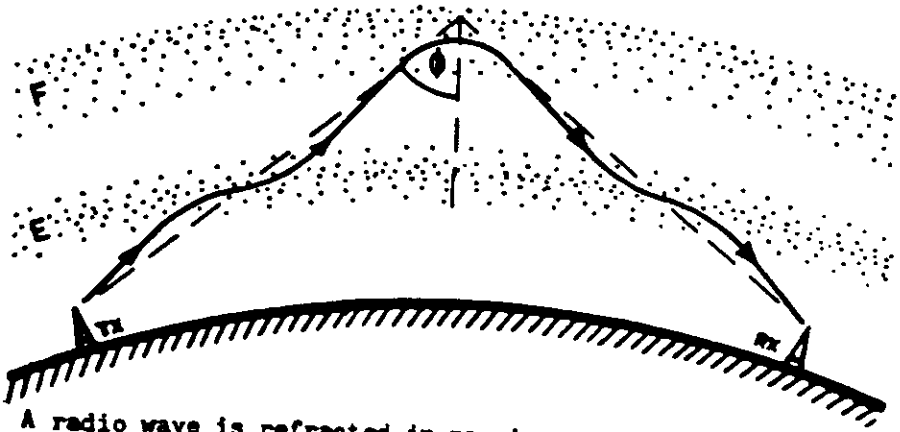


Figure 15d) $N_e(h)$ model used in the International Reference Ionosphere.



A radio wave is refracted in passing through two layers but can be represented by a single triangulated reflected ray.

(from Australian, IPS 1982)

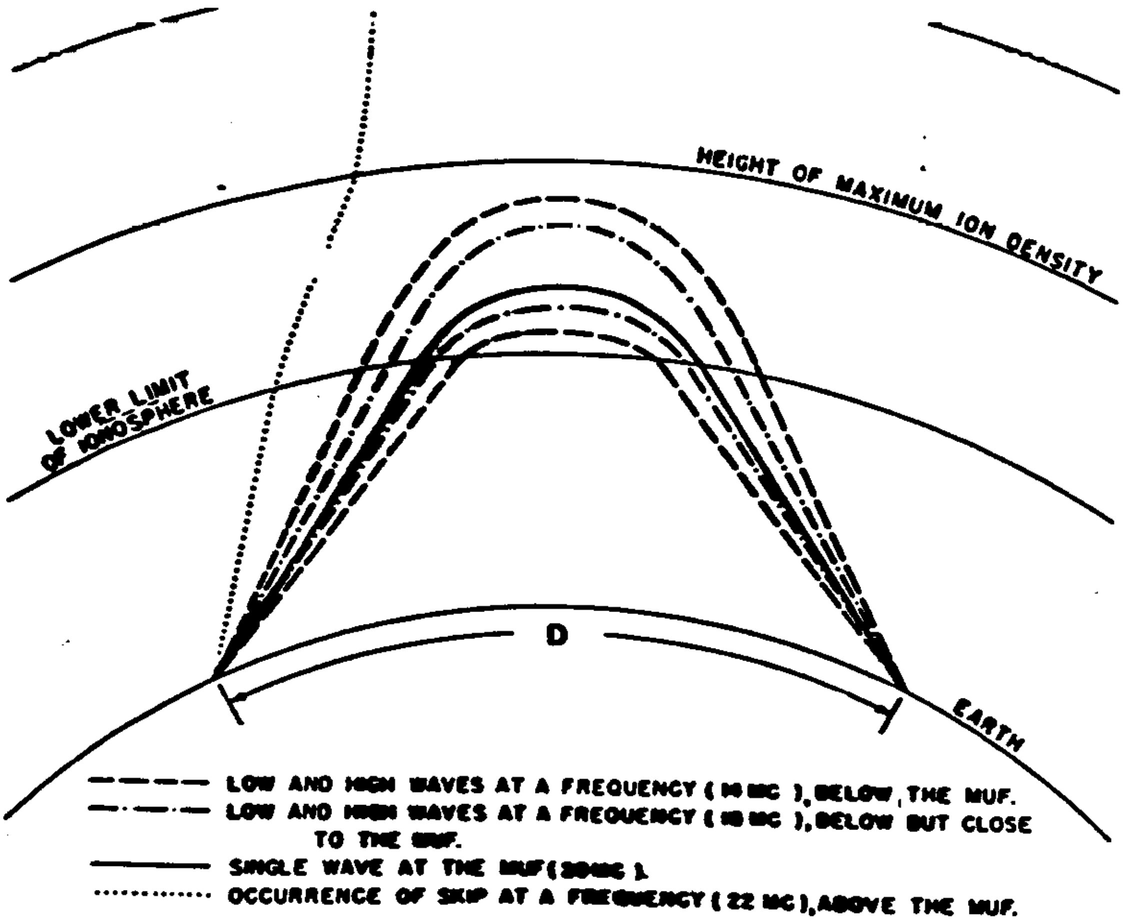
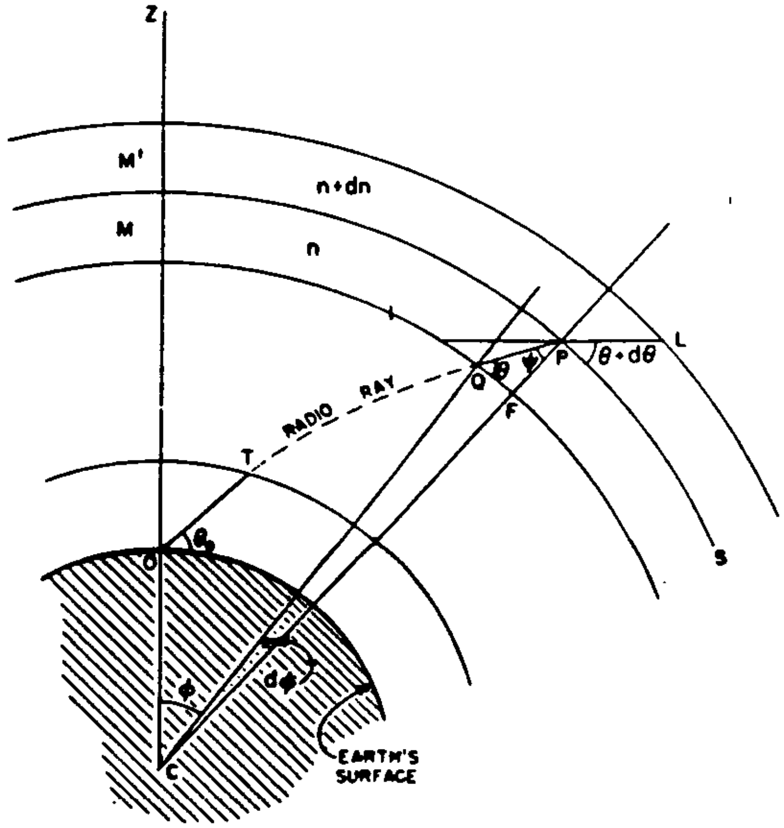


FIGURE 6.3. *Fixed distance—varying frequency (curved earth, curved ionosphere assumed)*

(from NBS 462, 1948)



Geometry for the derivation of Snell's Law in spherical coordinates.
(from Bean and Dutton, 1968)

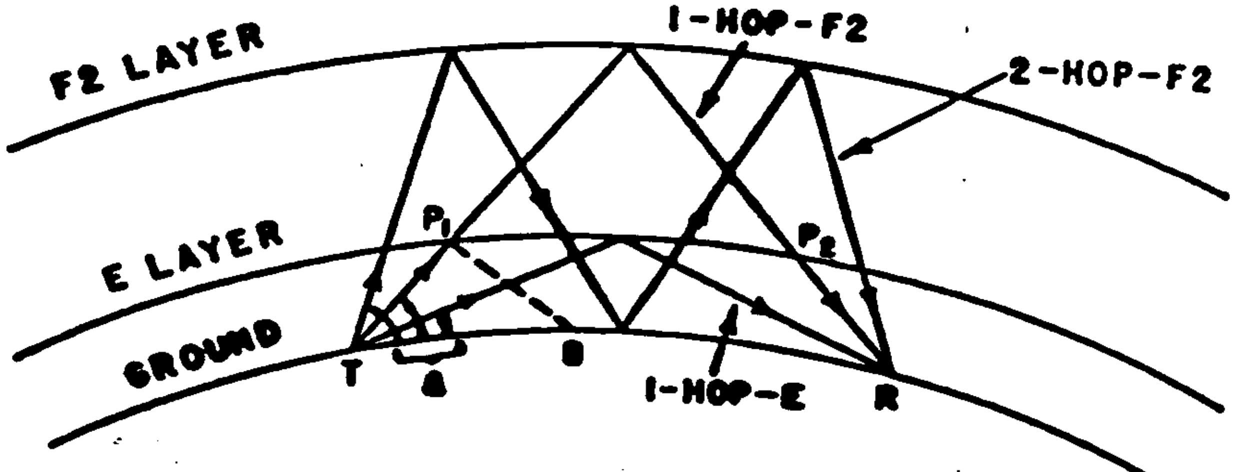
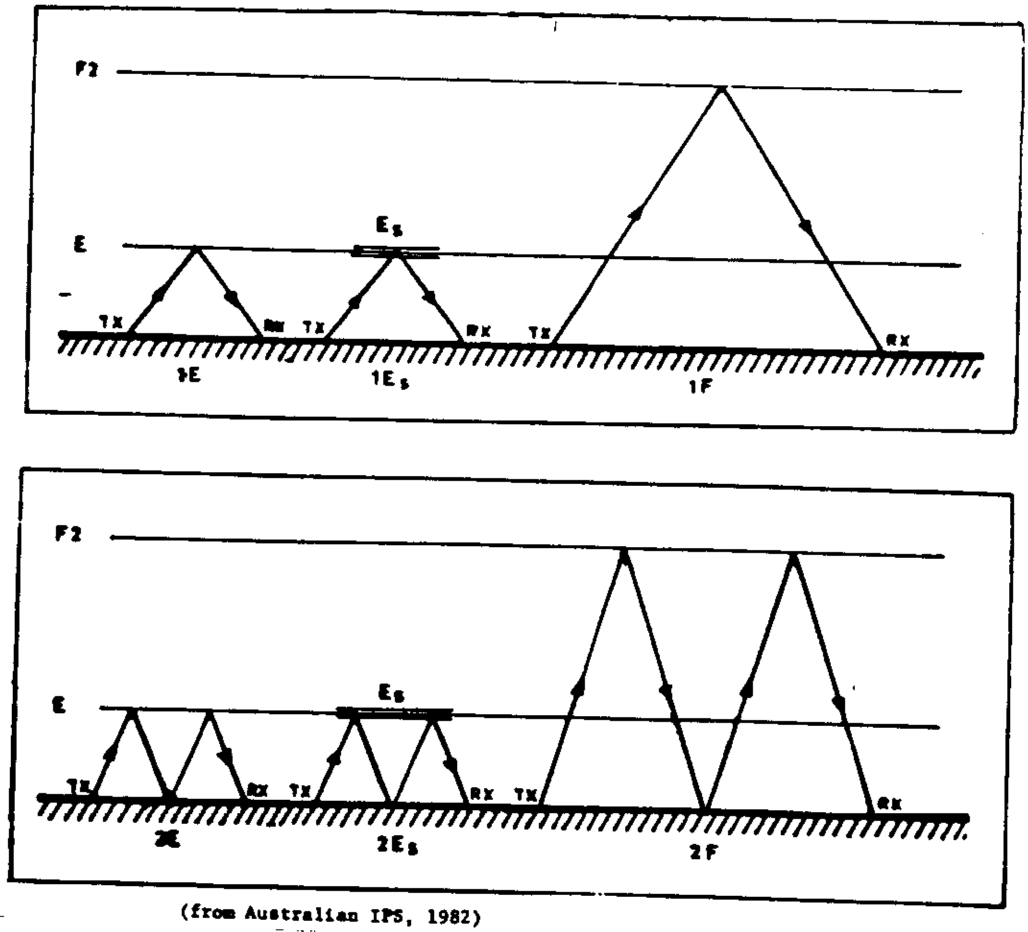
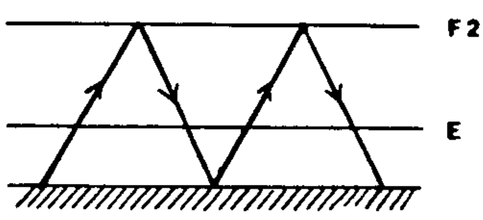


FIGURE 7.1. *Modes of propagation.*

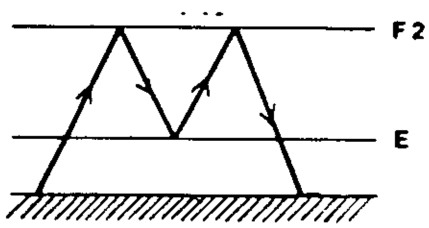
(from [illegible] Circular 462, 1948)



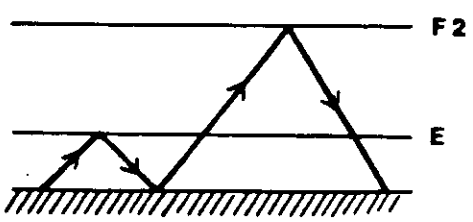
(from Australian IPS, 1982)



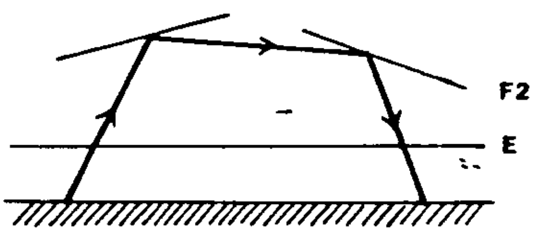
a) 2 F2 mode



b) M - mode

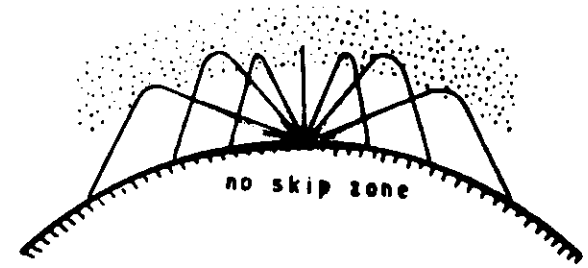


c) 1E + 1F2 mode



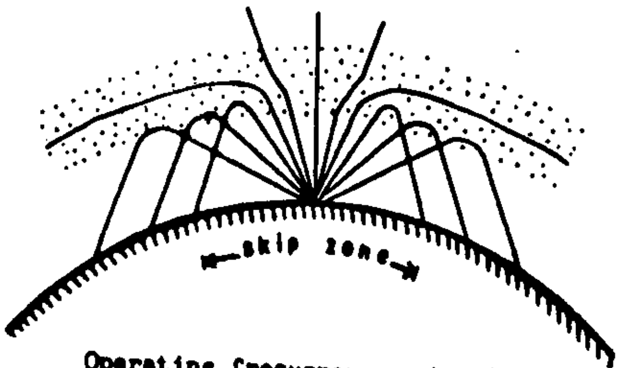
d) Mode in an ionosphere with tilts

SKIP ZONE



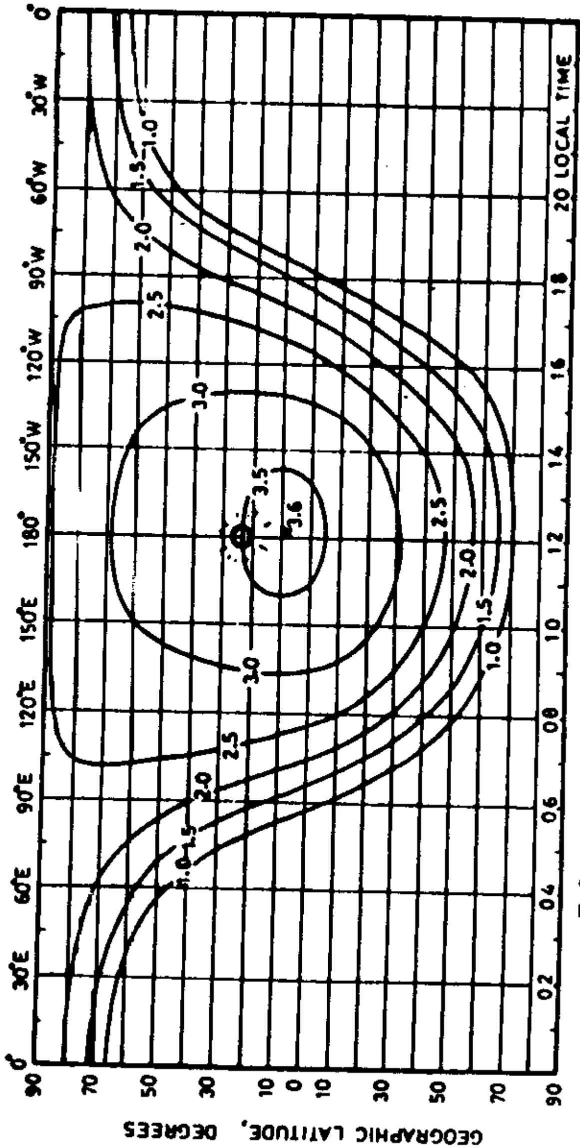
Operating frequency less than the critical frequency of the ionosephere.

(from Australian IPS, 1982)

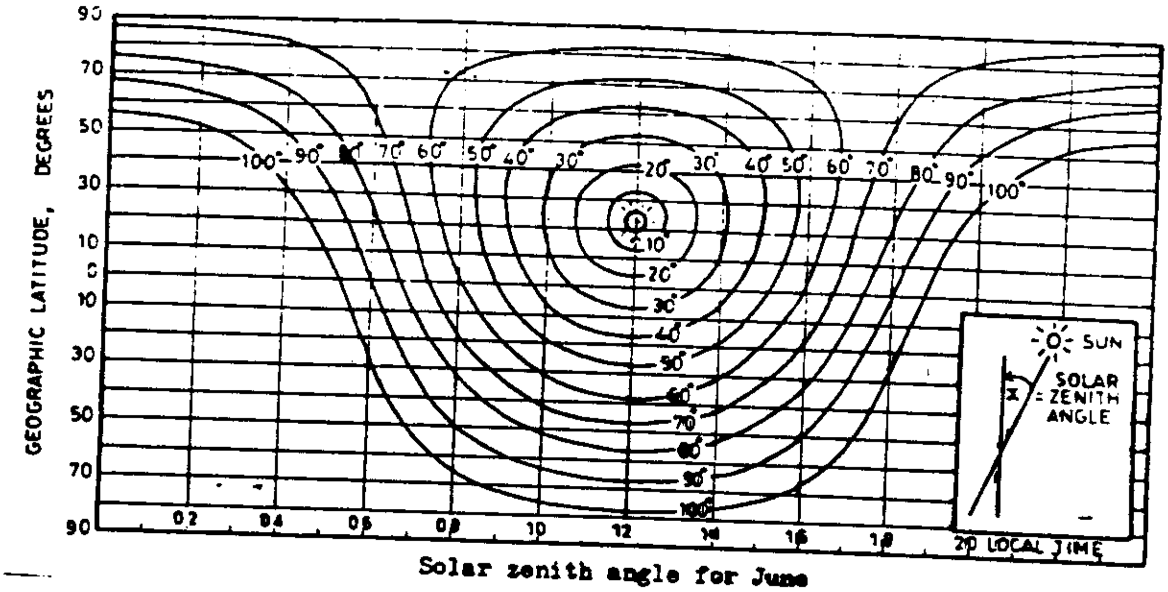


Operating frequency greater than the critical frequency of the ionosphere.

(from Australian IPS, 1982)

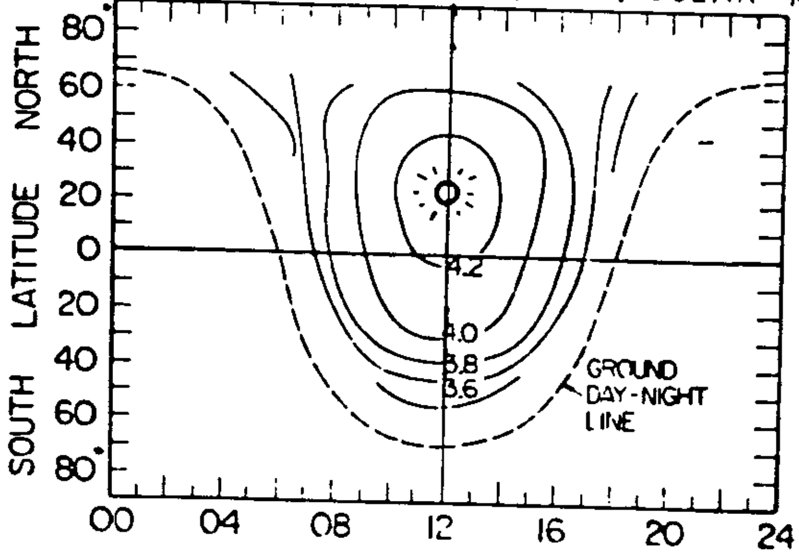


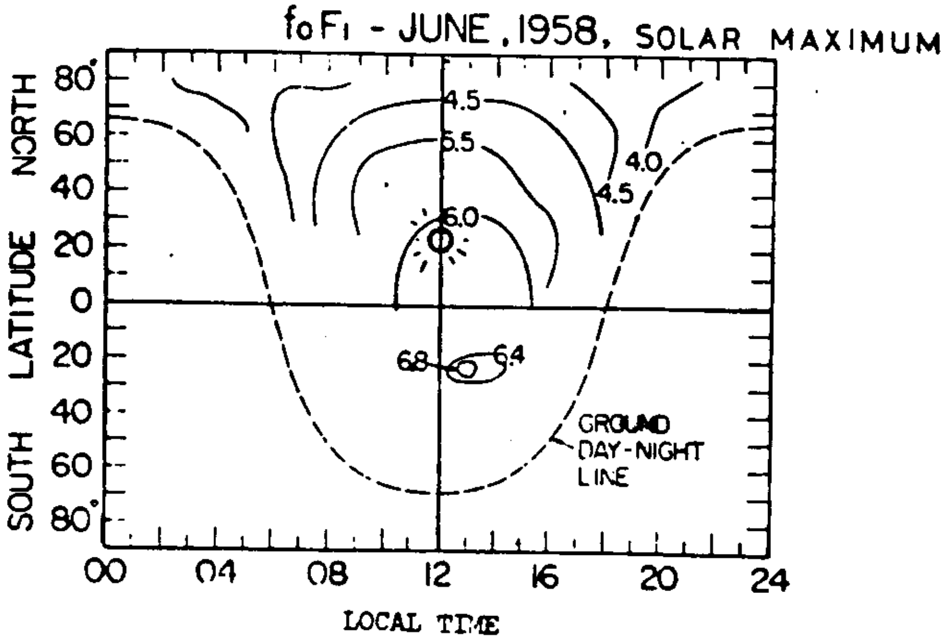
E-layer critical frequencies (MHz) for June, solar minimum



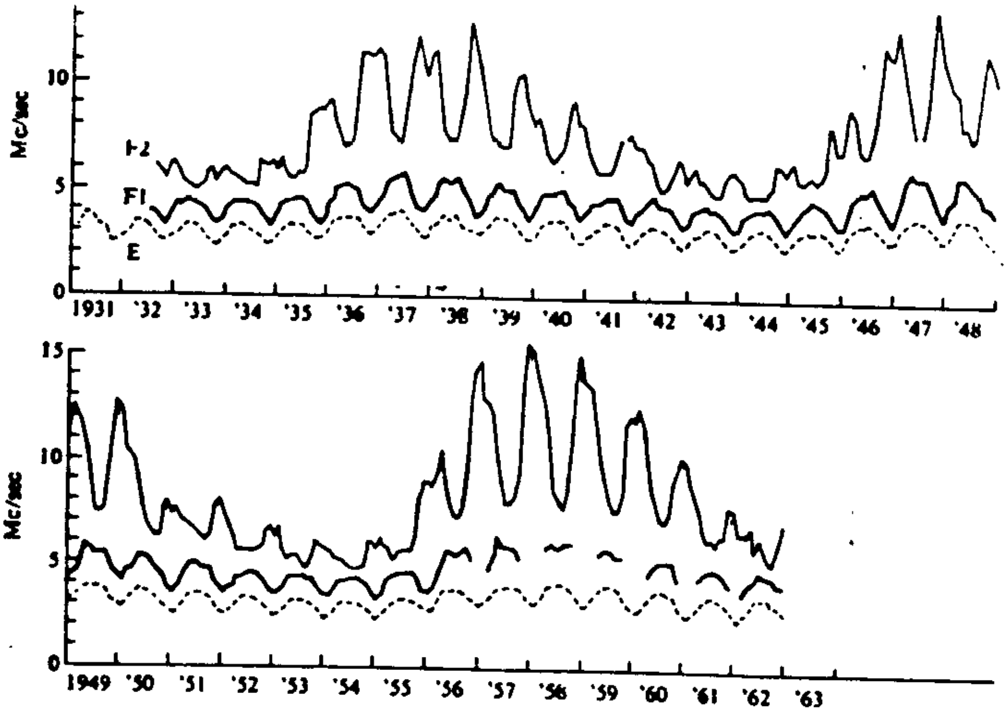
Solar zenith angle for June

foF1 - JUNE, 1954, SOLAR MINIMUM





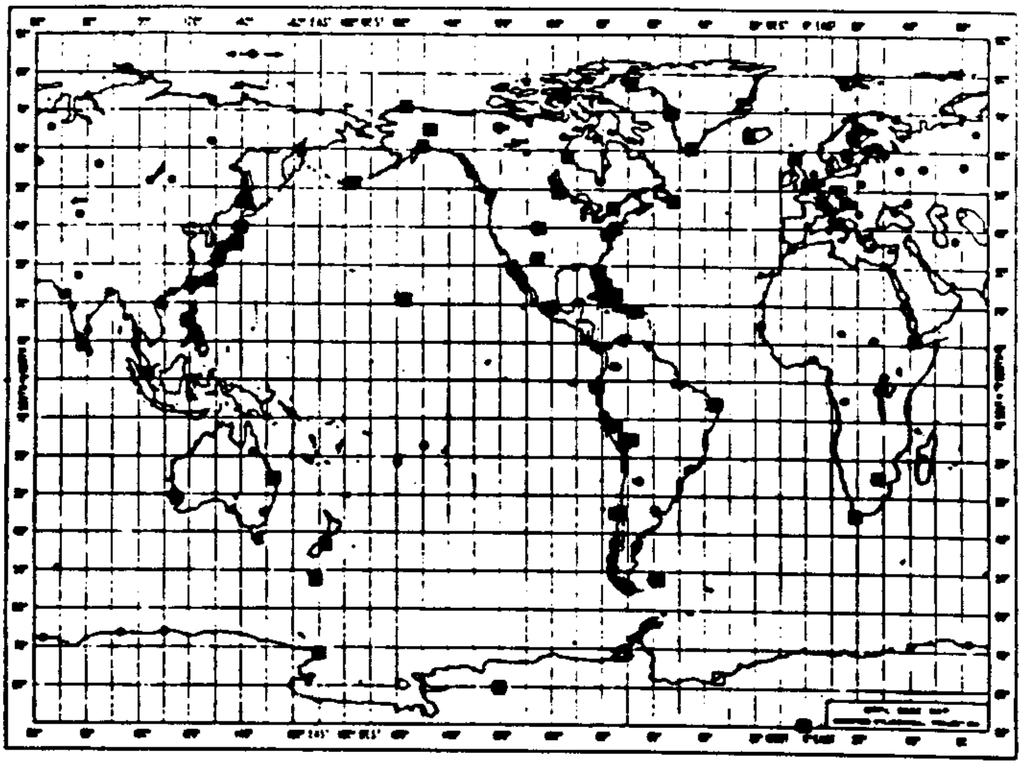
F1-layer critical frequencies(MHz)



Long term variations of critical frequencies at Slough, England (Davies 1969).

IONOSPHERIC VERTICAL SOUNDING STATIONS

[● = 1959 DATA IN WDC-A]
[□ = 1961 DATA IN WDC-A]



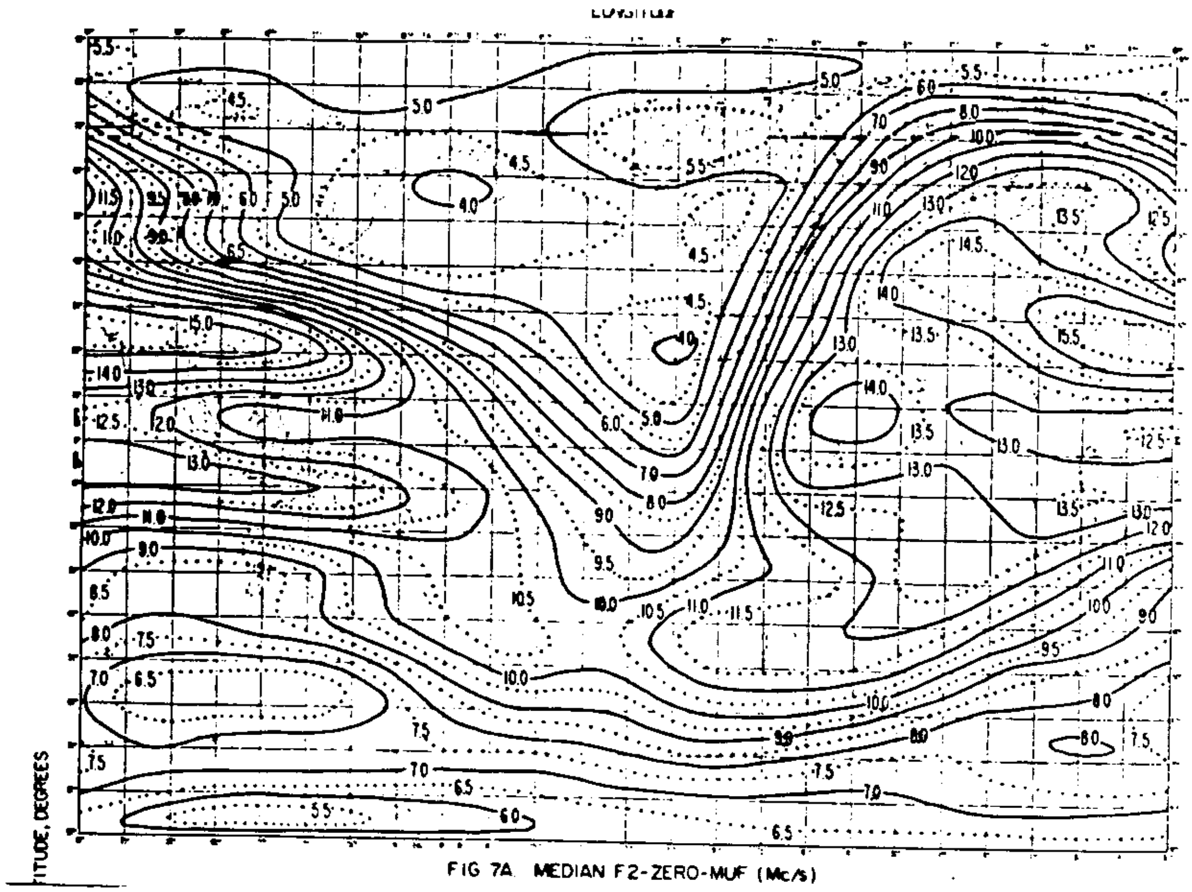


FIG 7A. MEDIAN F2-ZERO-MUF (Mc/s)

(from NBS 90, 1962)

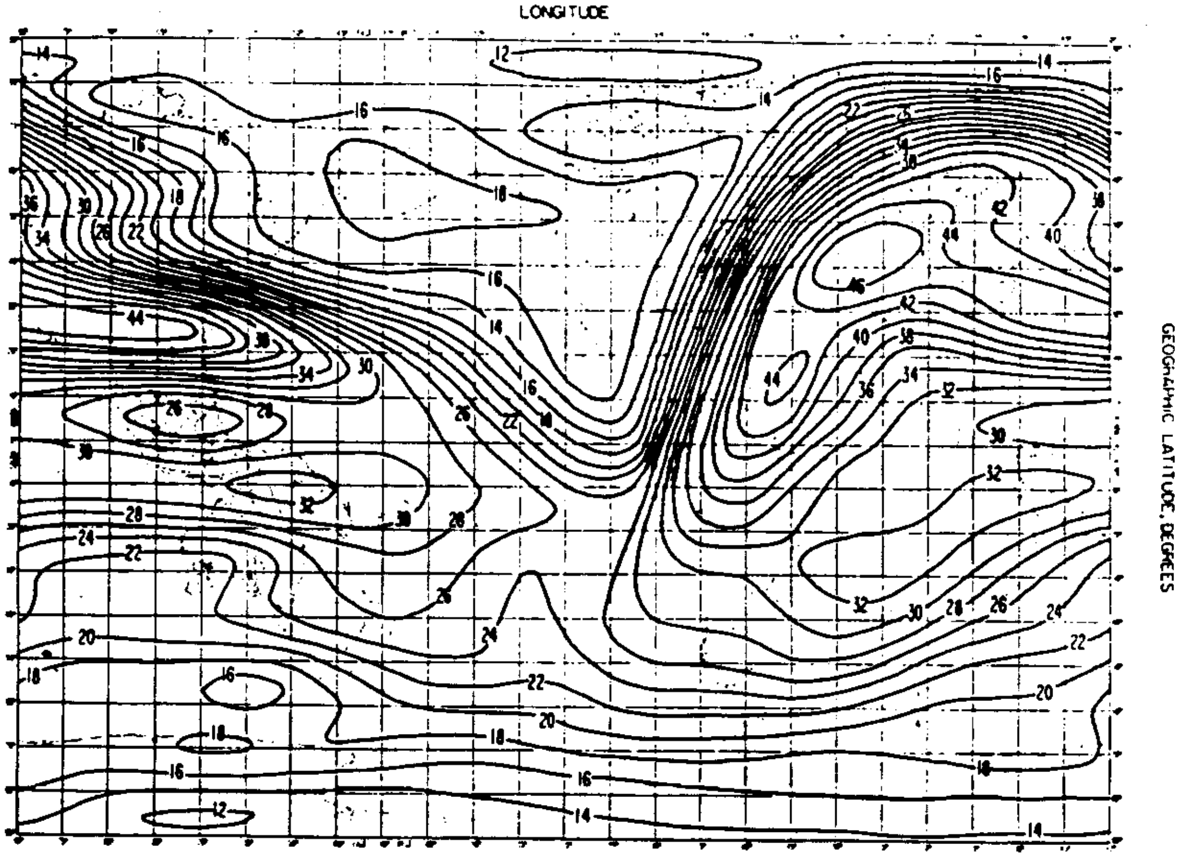
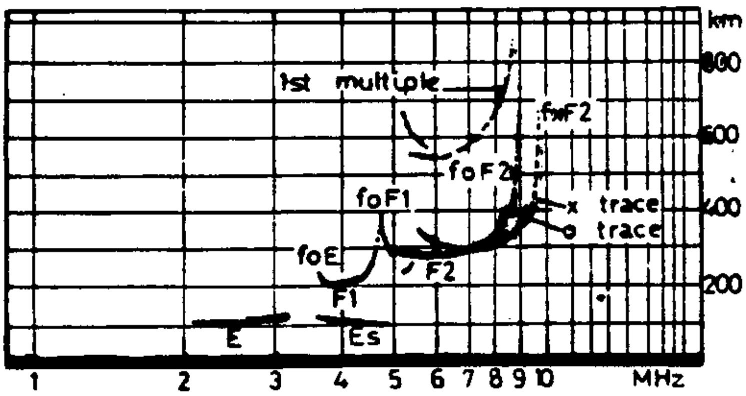


FIG. 7B MEDIAN F2-4000-MUF (Mc/s)

(from NBS 90, 1962)



NORMAL DAY TIME IONOGRAM

The polarised ordinary (o) and extraordinary (x) components, the critical frequencies of the E, F1 and F2 layers, a sporadic-E layer and a multiple echo are shown.

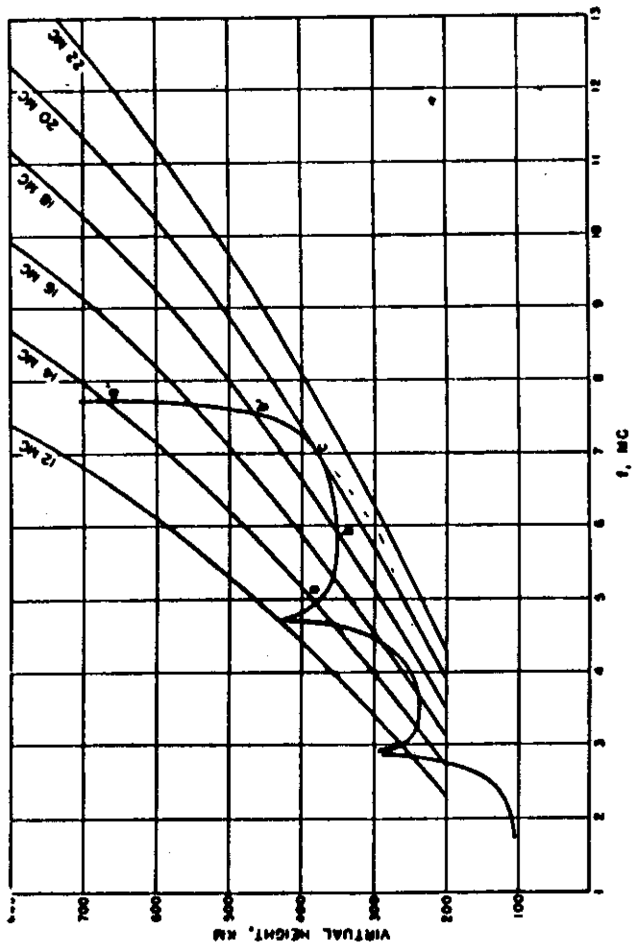
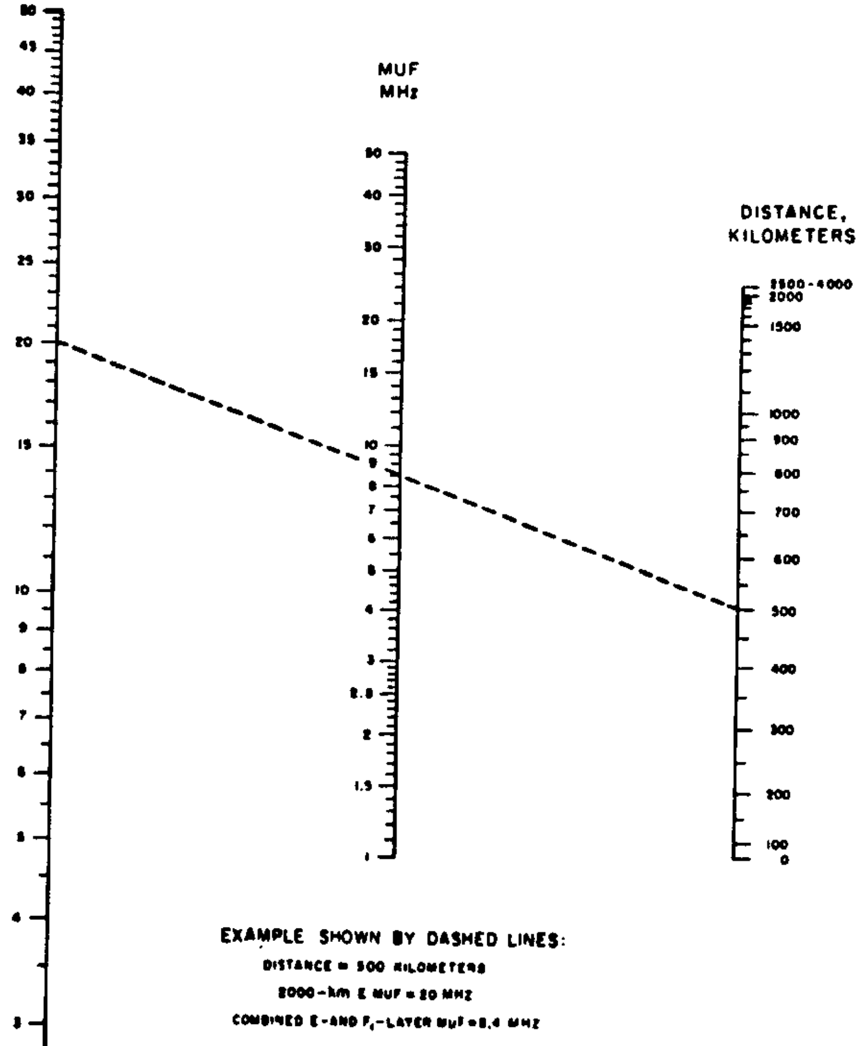
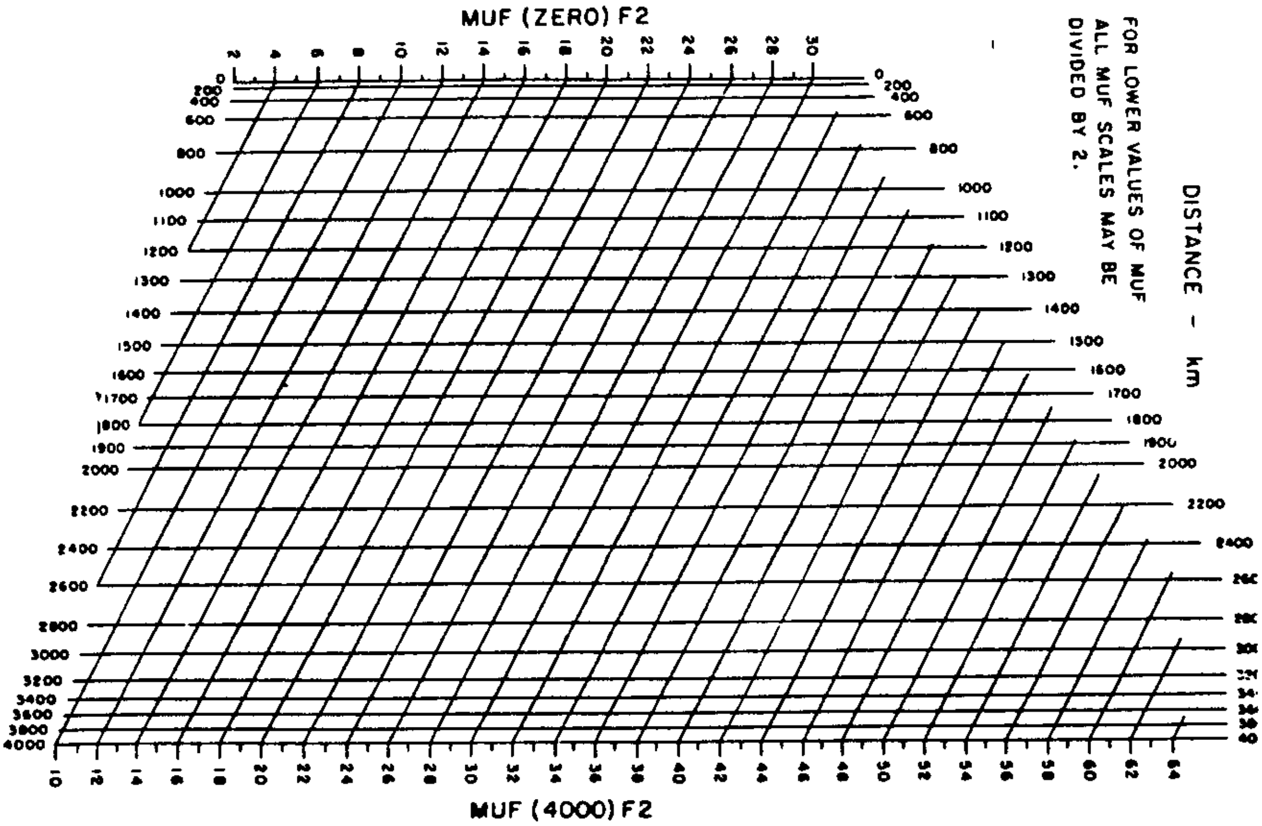


FIGURE 6.2. *Family of transmission curves parametric in frequency for a fixed distance of 2,000 km superimposed on an h'f graph.*
A flat earth and flat ionosphere assumed.



NOMOGRAM FOR CONVERTING THE MUF(2000)E TO MUFS AT OTHER DISTANCES INCLUDING F1-REGION EFFECTS AT DISTANCES GREATER THAN 2000 km.

(from ITS-OT/TRER 13, Sept. 1971)



Nomogram for Interpolaring Between MUF (ZERO)F2 and MUF ([redacted])F2 to Obtain MUFs at Intermediate Distances
(from ITS-OT/TRER 13, Sept. 1971)

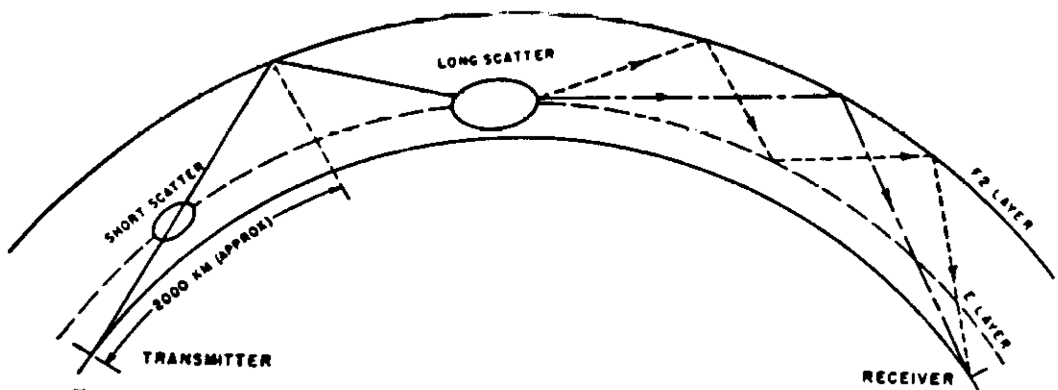
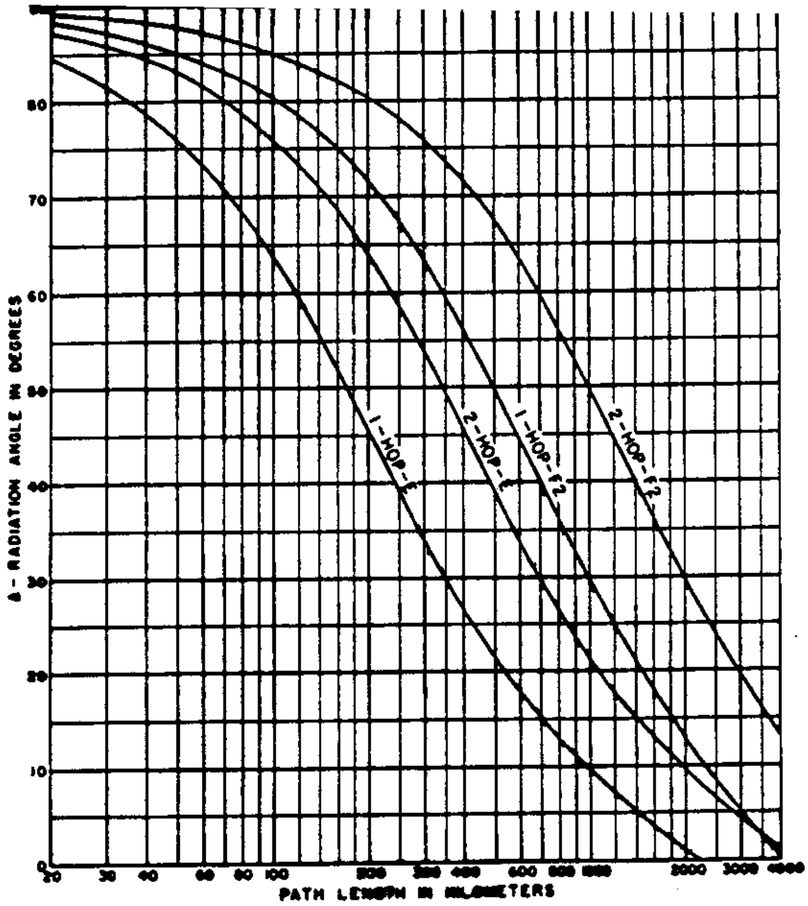


FIGURE 6.9. *Some possible modes of propagation over great distances involving long scatter.*

(from NBS Circular 462, 1948)



Radiation angle versus path length, based on virtual reflection heights, E layer—105 km, F2 layer—320 km.

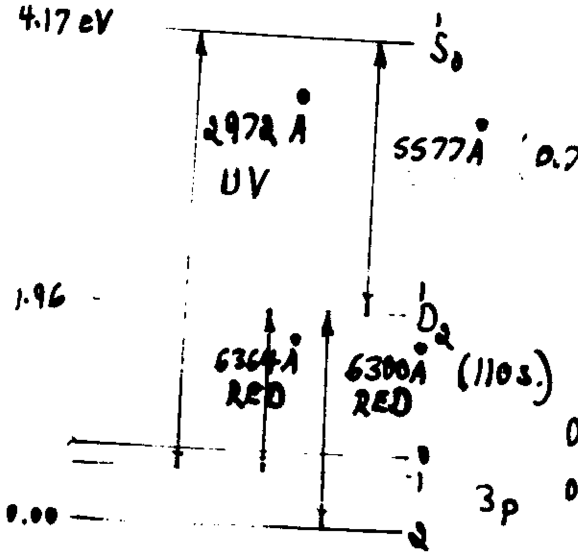
(from NBS Circular 462, 1948)

Path Length Kilometres	Required Radiation (Elevation) Angles	Suitable Simple Aerial
0–200	60°– 90°	Horizontal dipole: broadside to required azimuth. 0.25 wavelength (λ) above ground.
200–500	40°– 70°	Horizontal dipole: broadside to required azimuth. 0.3 λ above ground.
500–1000	25°– 50° and 10°– 20°	0.25λ vertical monopole, or horizontal dipole, broadside to required azimuth 0.5 λ above ground.
1000–2000	10°– 30° and low angles	Vertical monopole up to 0.3λ long with ground screen.
2000–3000	5°– 15° and 20 - 30°	Vertical monopole up to 0.3λ long.
>3000	low angles	Vertical monopole up to 0.6 λ long with ground screen.

Examples of path lengths and simple aerials suitable for the required radiation angles.

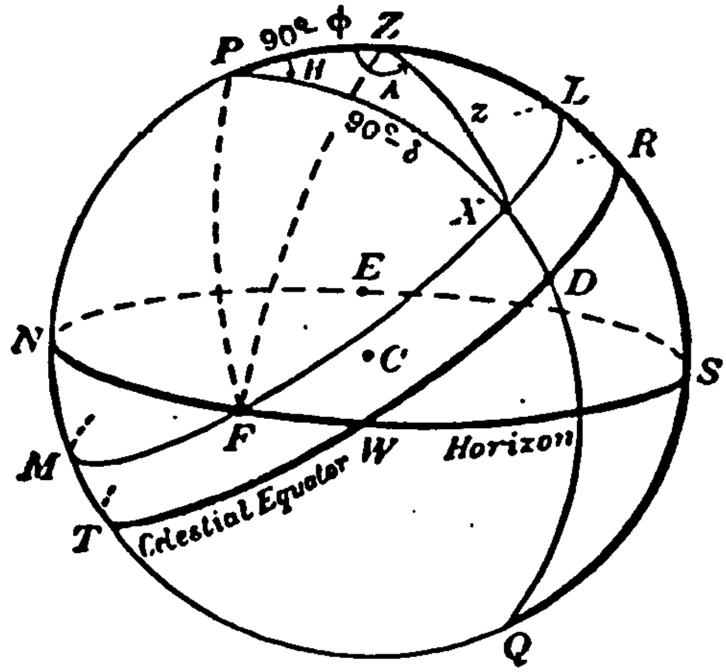
(from Australian IPS, 1982)

OPTICAL EMISSIONS



$O_2^+ + e \rightarrow O^* + O^*$

DISSOCIATIVE RECOMBINATION



$\cos z = \sin\phi \sin\delta + \cos\phi \cos\delta \cos H$

$\sin\delta = \sin\phi \cos z + \cos\phi \sin z \cos A$

(from Smart, 1960)

ϕ = latitude
δ = celestial declination
H = " hour angle
A = azimuth
z = zenith distance (90° - elevation)

Radius vector

$$\rho = a(0.998\ 327\ 073 + 0.001\ 676\ 438 \cos 2\phi - 0.000\ 003\ 519 \cos 4\phi + 0.000\ 000\ 008 \cos 6\phi)$$

One degree of latitude (m)

$$111\ 133.35 - 559.84 \cos 2\phi + 1.17 \cos 4\phi \quad (\phi = \text{mid-latitude of arc})$$

One degree of longitude (m)

$$111\ 413.28 \cos \phi - 93.51 \cos 3\phi + 0.12 \cos 5\phi$$

Figure of the Earth

Equatorial radius (primary)	$a = 6\ 378\ 160$ m
Flattening factor for Earth (derived)	$f = 1/298.25$
	$= 0.003\ 352\ 89$
Polar radius	$a(1-f) = 6\ 356\ 774.7$ m
Square of eccentricity	$e^2 = 0.006\ 694\ 54$

Reduction from geodetic latitude ϕ to geocentric latitude ϕ'

$$\phi' - \phi = -11'\ 32''.743\ 0 \sin 2\phi + 1''.163\ 3 \sin 4\phi - 0''.002\ 6 \sin 6\phi$$

*The complete system of astronomical constants is given in *Supplement to the A.E.* 1968 (pages 4s-7s).

(from The American Ephemeris and Nautrical Almanac 1975. [redacted]...)

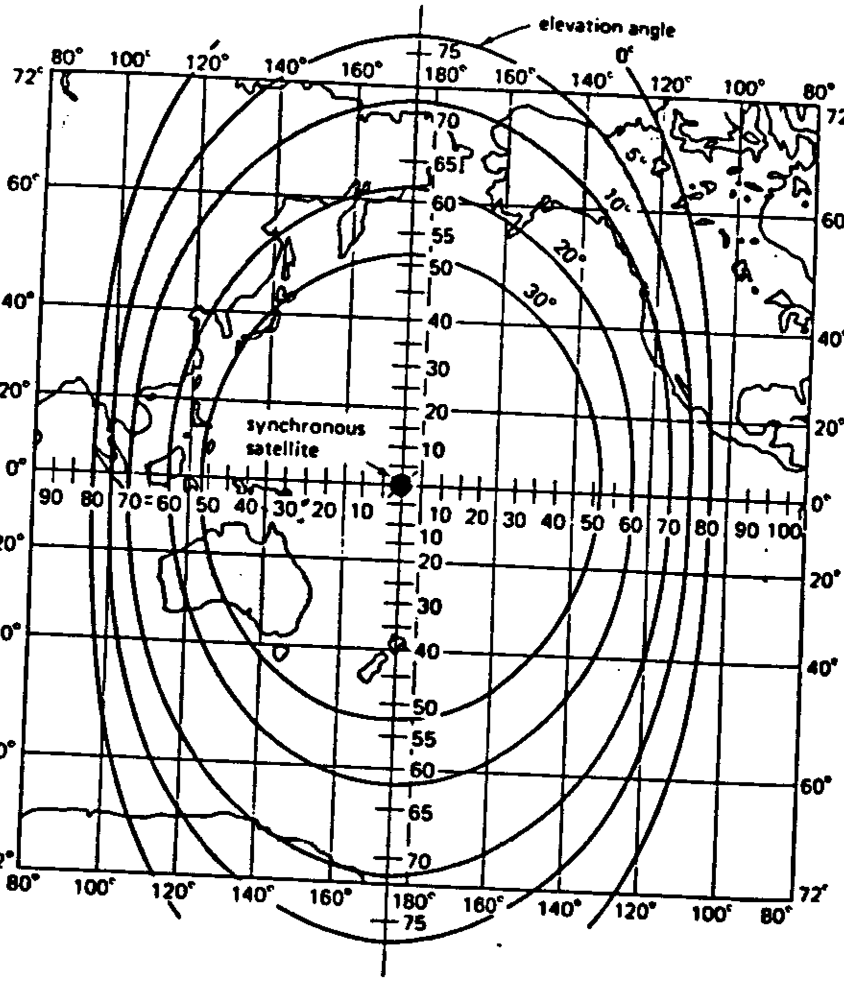


Fig. 6-15 Synchronous-satellite coverage pattern versus ground-station elevation angle

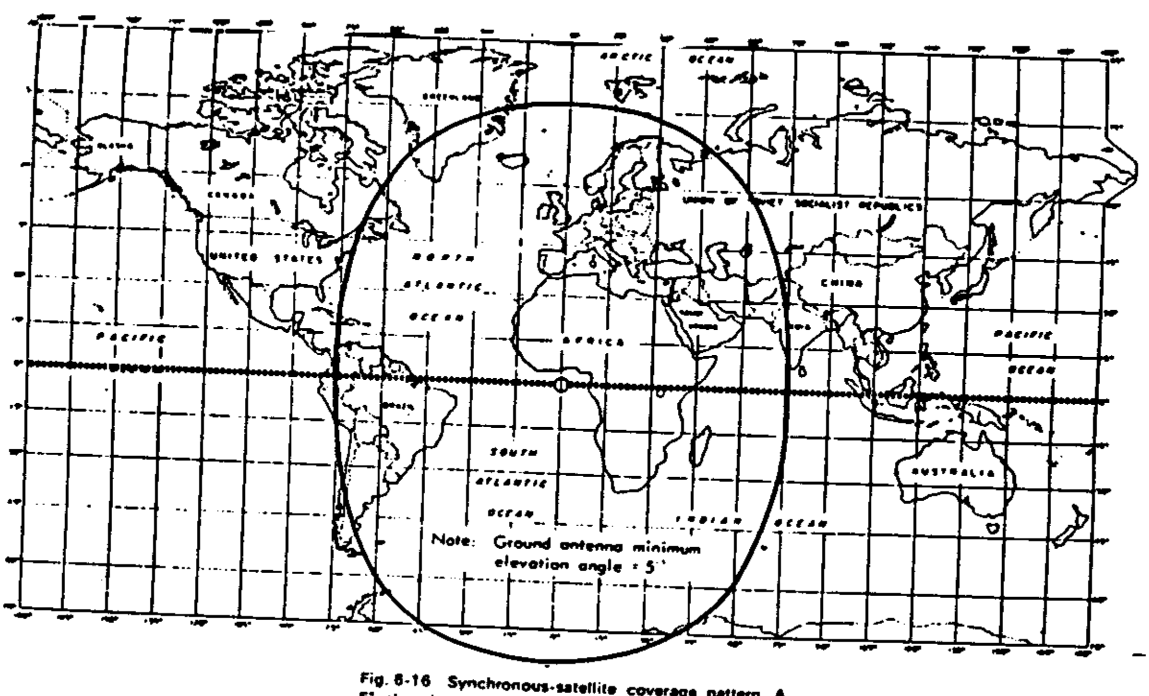


Fig. 6-16 Synchronous-satellite coverage pattern. A 5° elevation angle from the 19,310 nm synchronous altitude covers 25.8% of the earth's surface.

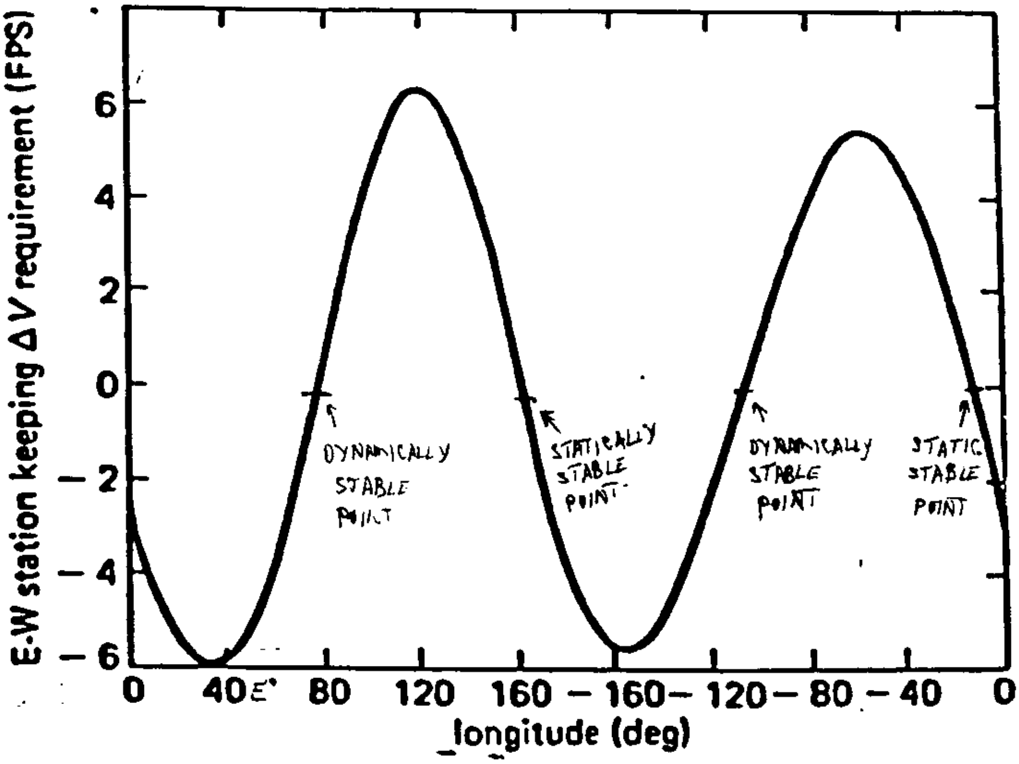


Fig. 6-3 Geosynchronous satellite east-west velocity corrections in feet per second [Isley and Duck article, reprinted from *Communications Satellite Technology*, P. Bargellini ed., by permission of the M. I. T. Press, Cambridge, MA, © 1974. All rights reserved.]

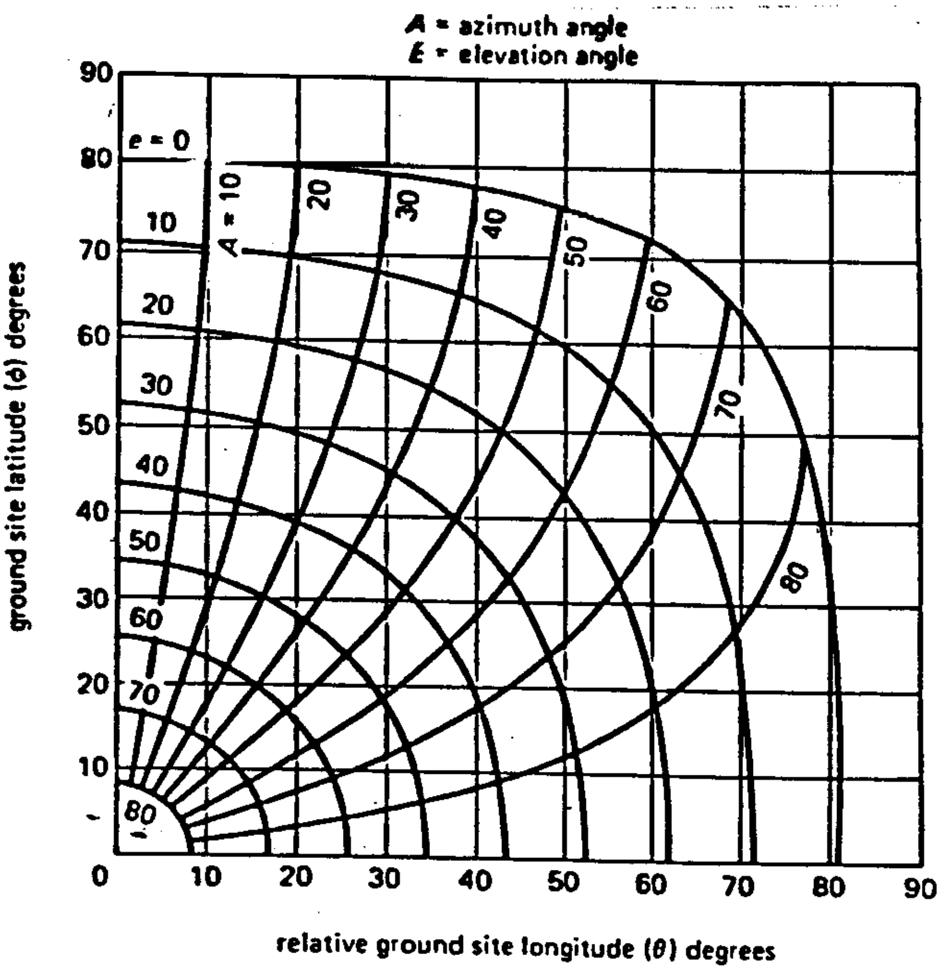


Fig. 6-18 Azimuth and elevation look angles to geostationary satellites [From F. L. Smith, 1972]

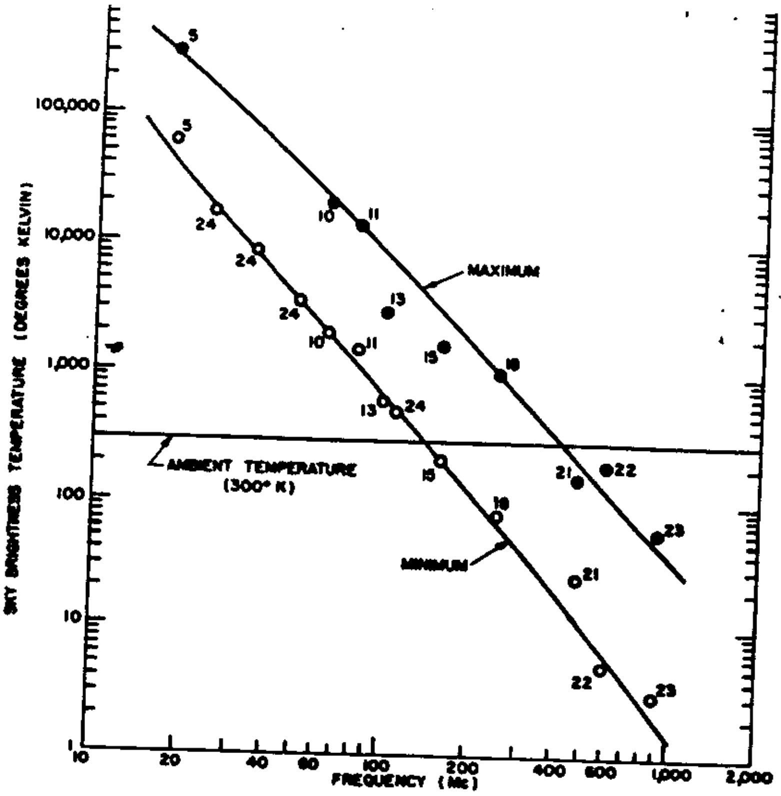
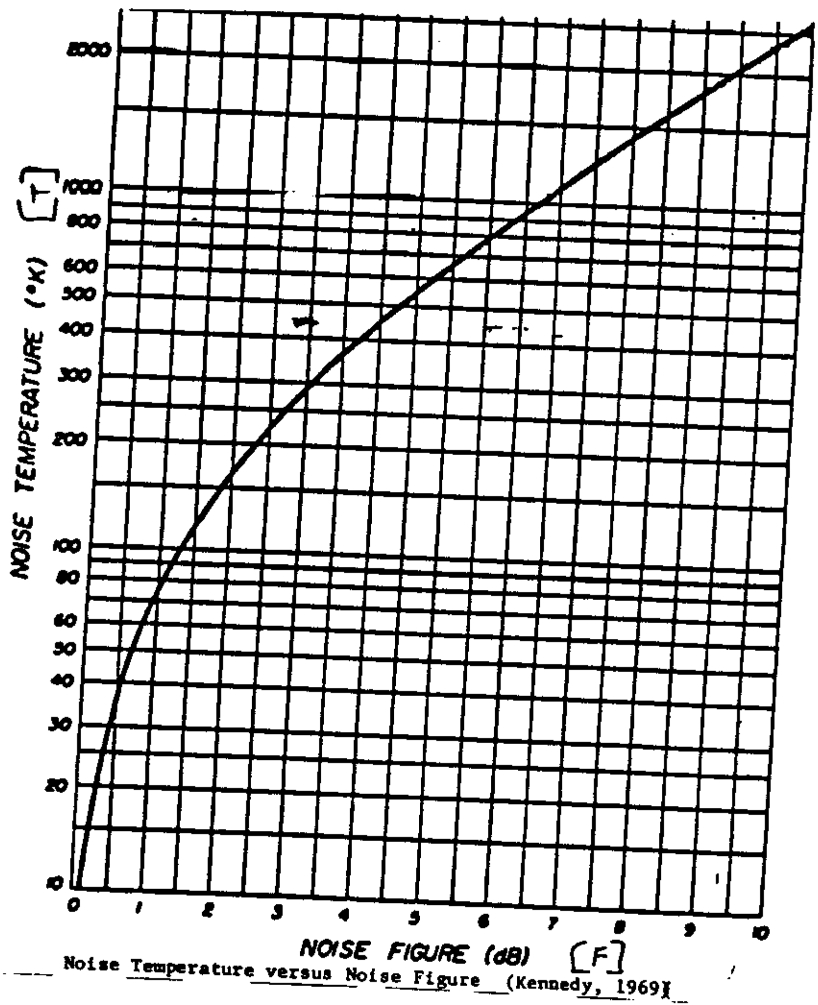


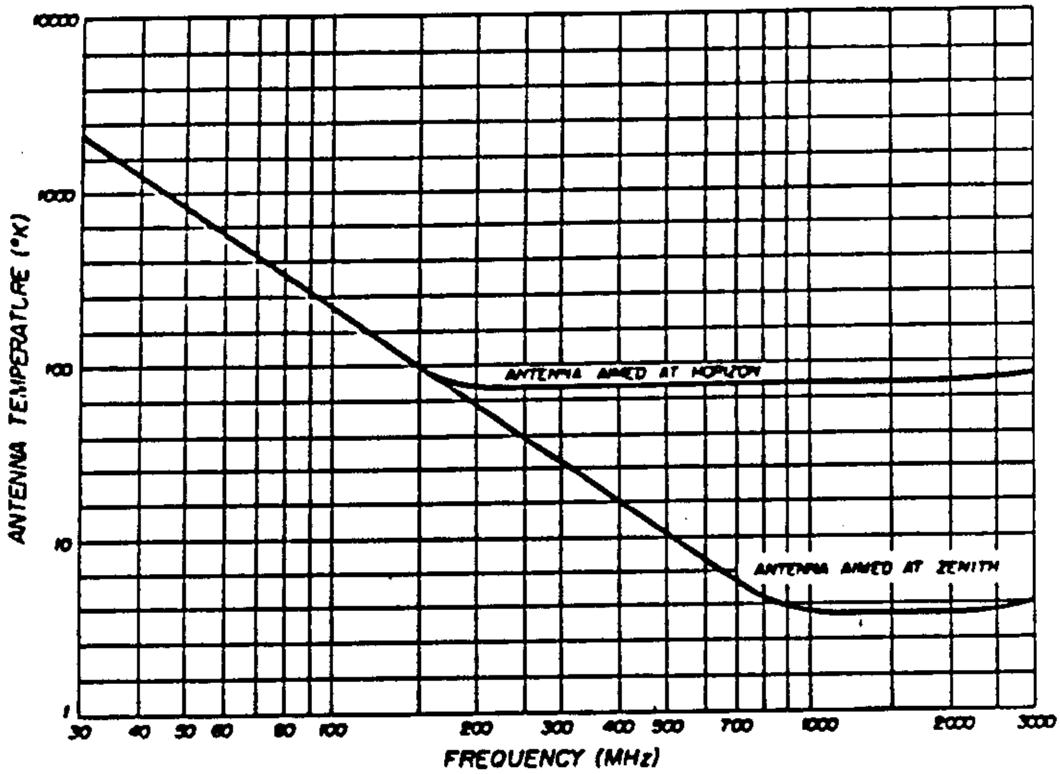
Fig. 21. Maximum and minimum sky temperatures as a function of frequency. The numbers adjacent indicate observers (see references).

(after Kraus, 1958)



Noise Temperature versus Noise Figure (Kennedy, 1969)

$T = \left[10^{(F/10)} - 1\right] * 290°$



Minimum Expected Antenna Temperature as a Function of Frequency (Kennedy, 1969)

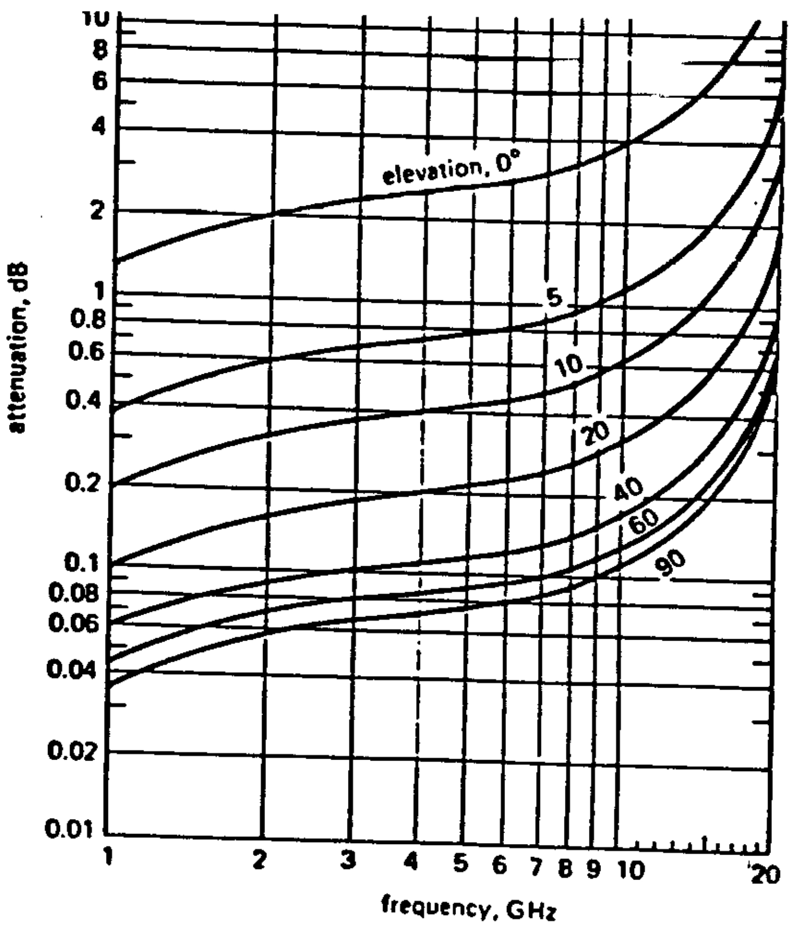


Fig. 6-32 Atmospheric attenuation due to oxygen and water vapor [From Benoit, 1968, 73–80]

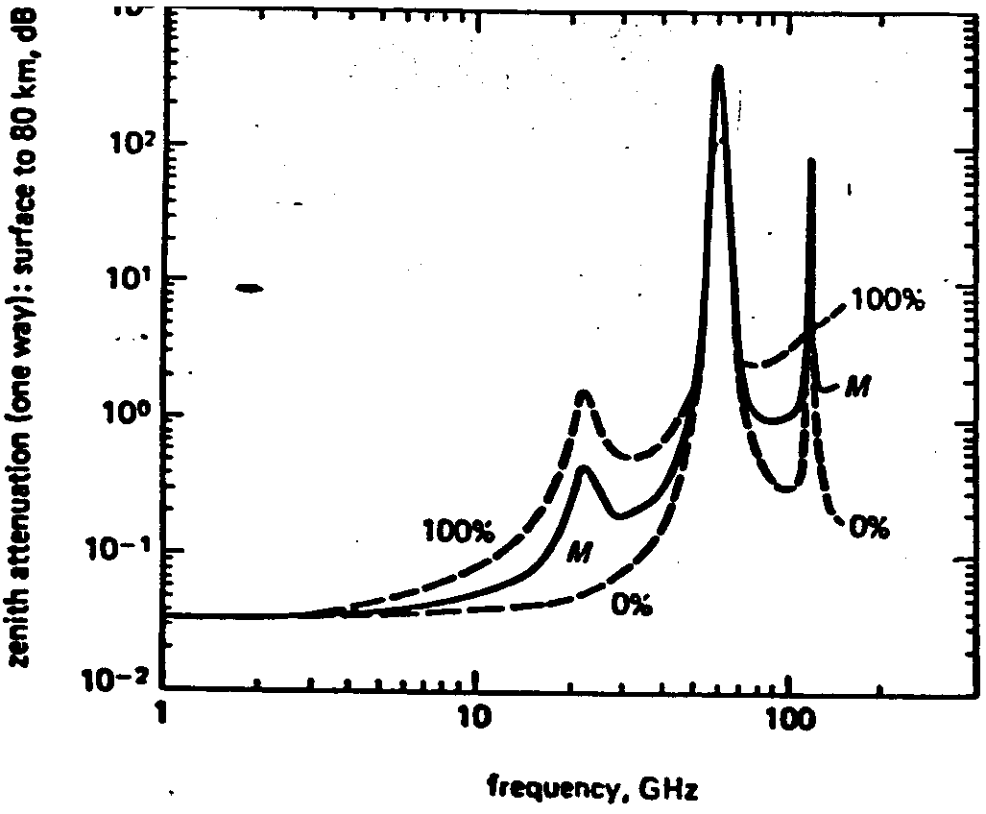
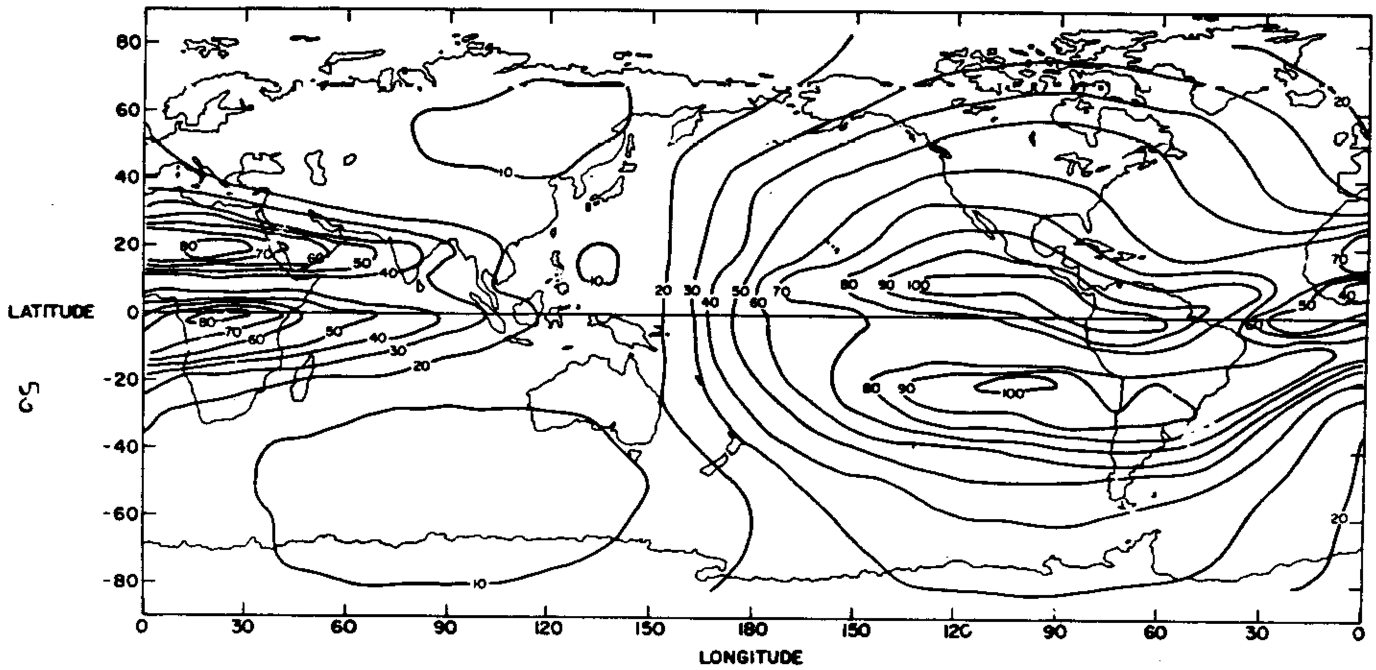
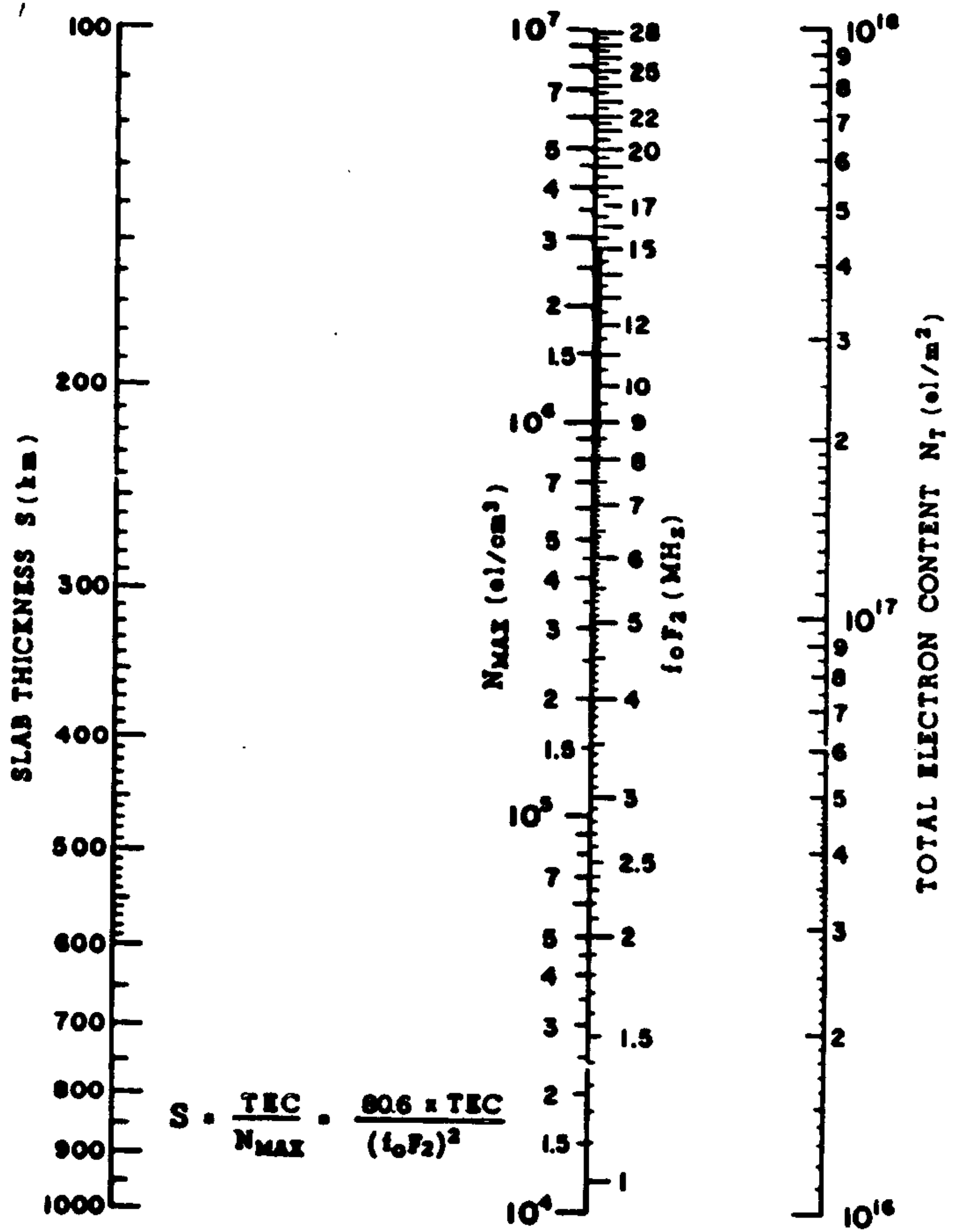


Fig. 6-31 Zenith attentuation versus frequency for various percent humidity [From Crane, 1971, 174]



CONTOURS OF TOTAL ELECTRON CONTENT UNITS OF 10^{16} el / m^2 COLUMN
MARCH 1980 ($F_{10.7}$ = 167)
2000 UT

AFCRL (TEC) - SLAB THICKNESS NOMOGRAPH



$$S = \frac{TEC}{N_{MAX}} = \frac{80.6 \times TEC}{(f_oF_2)^2}$$