The information contained within Appendix A is taken from CCIR Report 575, Sky-wave Field Strength Prediction Method for the Frequency Range 150 to 1600 kHz, published in Volume VI of the Proceedings of the XIIIth Plenary Assembly, Geneva, 1974.

ANNEX

SKY-WAVE FIELD STRENGTH PREDICTION METHOD
FOR THE FREQUENCY RANGE 150 TO 1600 kHz

Method proposed by Interim Working Party 6/4
(Modified U.S.S.R. method)

List of symbols

b	Solar-activity factor given in § 2.6.
d	Ground distance between transmitter and receiver (km).
F_0	Annual median field strength at the reference time defined in § 2 (dB (μV/m)).
F_t	Annual median field strength at time t (dB (μV/m)).
f	Frequency (kHz).
f'	A frequency defined in equation (6) (kHz).
G_0	Sea gain for a terminal on the coast (dB).
G_H	Transmitting antenna gain factor due to horizontal directivity (dB).
G_S	Sea gain for a terminal near the sea (dB).
G_V	Transmitting antenna gain factor due to vertical directivity (dB).
h	Transmitting antenna height (Fig. 6).
h_r	Height of reflecting layer (km).
I	Magnetic dip angle (degrees).
k	Basic loss factor.
k_R	Loss factor.
L_P	Excess polarisation coupling loss (dB).
L_t	Diurnal loss factor (dB).
P	Radiated power (dB (1 kW)).
p	Slant propagation distance (km).
Q	A sea-gain parameter given in § 2.3.
R	Twelve-month smoothed Zurich sunspot number.
s	Distance of terminal from sea, measured along great-circle path (km).
t	Time relative to sunset or sunrise (hours).
V	Transmitter cymomotive force (dB (300 V)).
θ	Direction of propagation relative to magnetic East-West (degrees).
λ	Wavelength.
Φ	A geomagnetic latitude parameter.
Φ_T	Geomagnetic latitude of transmitter } (degrees, positive in northern hemisphere, negative in southern hemisphere).
Φ_R	Geomagnetic latitude of receiver } (degrees, positive in northern hemisphere, negative in southern hemisphere).

1. Introduction

This method of prediction gives the night-time sky-wave field strength produced for a given power radiated from one or more vertical antennae, when measured by a loop antenna at ground level aligned in a vertical plane along the great-circle path to the transmitter. It applies for paths of lengths up to 12 000 km. However in band 5 it was only verified for paths of up to 5000 km. The accuracy of prediction varies from region to region and may be improved in certain regions by applying modifications such as those shown in § 5. In any case the method should be used with caution for geomagnetic latitudes greater than 60°.

2. Annual median night-time field strength

The predicted sky-wave field strength is given by:

$$F_0 = V + G_S - L_P + 105{\cdot}3 - 20 \log_{10} p - 10^{-3}\, k_R p \tag{1}$$

where F_0 = annual median of half-hourly median field strengths (dB above 1 μV/m) at the reference time defined in § 2.1.

V = transmitter cymomotive force, dB above a reference cymomotive force of 300 V,

G_S = sea-gain correction, dB,

L_P = excess polarization-coupling loss, dB,

p = slant-propagation distance, km,

k_R = loss factor incorporating effects of ionospheric absorption, focusing and terminal losses, and losses between hops on multi-hop paths.

2.1 *Reference time*

The reference time is taken as six hours after the time at which the sun sets at a point S on the surface of the Earth. For paths shorter than 2000 km, S is the mid-point of the path. On longer paths, S is 750 km from the terminal where the sun sets last, measured along the great-circle path.

2.2 *Cymomotive force*

The cymomotive force V is given as:

$$V = P + G_V + G_H \tag{2}$$

where P = radiated power, dB above 1 kW,

G_V = transmitting antenna gain factor (dB) due to vertical directivity, given in Fig. 6,

G_H = transmitting antenna gain factor (dB) due to horizontal directivity. For directional antennae, G_H is a function of azimuth. For omnidirectional antennae, $G_H = 0$.

2.3 *Sea gain*

G_S is the additional signal gain when one or both terminals is situated near the sea. G_S for a single terminal is given by:

$$G_S = G_0 - 10^{-3} \left(\frac{Q s f}{G_0} \right) \quad \text{dB} \tag{3}$$

where G_0 is the gain when the terminal is on the coast, f is the frequency in kHz and s is the distance in km of the terminal from the sea, measured along the great-circle path. $Q = 0{\cdot}44$ in band 5 and $1{\cdot}75$ in band 6. G_0 is given in Fig. 7 as a function of d for bands 5 and 6. In band 6, G_0 = 10 dB when $d > 6500$ km. Equation (3) applies for values of s such that $G_S > 0$. For larger values of s, $G_S = 0$. If both terminals are near the sea, G_S is the sum of the values of G_S for the individual terminals.

2.4 *Polarisation coupling loss*

L_P is the excess polarization coupling loss. In band 5, $L_P = 0$. In band 6 at low latitudes, for $|I| \leqslant 45°$

$$L_P = 180\,(36 + \theta^2 + I^2)^{-1/2} - 2 \quad \text{dB/terminal} \tag{4}$$

where I is the magnetic dip in degrees at the terminal and θ is the path azimuth measured in degrees from the magnetic E-W direction, such that $|\theta| \leqslant 90°$. For $|I| > 45°$, $L_P = 0$. L_P should be evaluated separately for the two terminals, because of the different θ and I that may apply, and the two L_P values added. The most accurate available values of magnetic dip and declination should be used in determining θ and I.

2.5 *Slant propagation distance*

For paths longer than 1000 km, p is approximately equal to the ground distance d (km). For shorter paths

$$p = (d^2 + 4h_r^2)^{1/2} \tag{5}$$

where $h_r = 100$ km if $f \leqslant f'$ and 220 km if $f > f'$, where f' (in kHz) is given by

$$f' = 350 + [(2{\cdot}8d)^3 + 300^3]^{1/3} \tag{6}$$

Equation (5) may be used for paths of any length with negligible error.

2.6 *Loss factor*

The loss factor k_R is given by

$$k_R = k + 10^{-2}\,bR \tag{7}$$

where R = twelve-month smoothed Zurich sunspot number. In band 5, $b = 0$. In band 6, $b = 4$ for North American paths, 1 for Europe and Australia and 0 elsewhere.

$$k = 1{\cdot}9\,f^{0{\cdot}15} + 0{\cdot}24\,f^{0{\cdot}4}\,(\tan^2\Phi - \tan^2 37°) \tag{8}$$

where f = frequency (kHz).

For paths shorter than 3000 km

$$\Phi = (\Phi_T + \Phi_R)\,/2 \tag{9}$$

where Φ_T and Φ_R are the geomagnetic latitudes at the transmitter and receiver respectively, determined by assuming an Earth-centred dipole field model with northern pole at 78·5°N, 69°W geographic co-ordinates. Φ_T and Φ_R are taken as positive in the northern hemisphere and negative in the southern hemisphere. Paths longer than 3000 km are divided into two equal sections which are considered separately. The value of Φ for each half-path is derived by taking the average of the geomagnetic latitudes at one terminal and at the mid-point of the whole path, the geomagnetic latitude at the mid-point of the whole path being assumed to be the average of Φ_T and Φ_R. As a consequence:

$$\Phi = (3\Phi_T + \Phi_R)/4 \quad \text{for the first half of the path and} \tag{10}$$

$$\Phi = (\Phi_T + 3\Phi_R)/4 \quad \text{for the second half.} \tag{11}$$

The values of k calculated from equation (8) for the two half-paths are then averaged and used in equation (7).

If $|\Phi| > 60°$, equation (8) is evaluated for $\Phi = 60°$.

3. Nocturnal variation of annual median field strength

$$F_t = F_0 - L_t \tag{12}$$

where F_t = annual median field strength at time t, dB (μV/m)

F_0 = annual median field strength at reference time defined in §2.1, dB (μV/m), given by equation (1)

L_t = diurnal loss factor, dB, given in Fig. 8.

Fig. 8 shows the average of the annual median nocturnal variations for Europe and Australia, derived from Fig. 8 of Report 264-3 and Fig. 5 of Report 431-1 respectively. The time t is the time in hours relative to the sunrise or sunset reference times as appropriate. These are taken at the ground at the mid-path position for $d < 2000$ km and at 750 km from the terminal where the sun sets last or rises first for longer paths.

4. Day-to-day and short-period variations of field strength

The field strength exceeded for 10% of the total time on a series of nights, during short periods centred on a specific time is:

8 dB greater in band 5

10 dB greater in band 6

than the values of F_0 and F_t given above.

5. Accuracy of the method

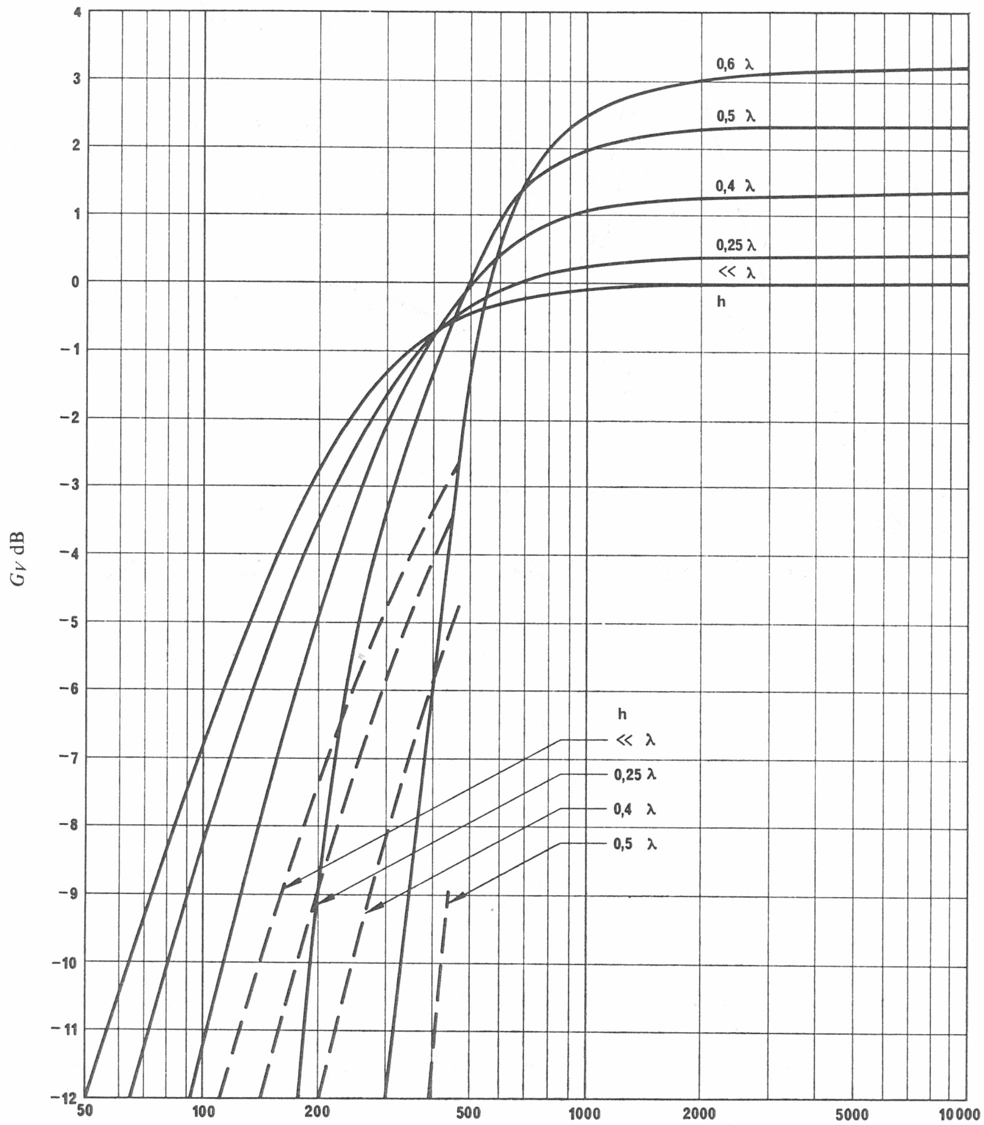
This method is believed to be reasonably accurate in I.T.U. Regions 1 and 3. Comparison of predicted and measured values shows, however, that its accuracy in certain regions may be further improved by making the following corrections.

5.1 Since field strengths measured in Australia and New Zealand are 4 to 7 dB higher than those predicted by the method, a better prediction formula for this area is

$$F_0 = V + G_s - L_P + 108 - 20 \log_{10} p - 0{\cdot}8 \times 10^{-3} k_R p \tag{13}$$

The field strength exceeded on band 6 for 10% of the total time on a series of nights, during short periods centred on a specific time, is only 7 dB greater than the annual median in this area.

5.2 The accuracy may be improved in North America by subtracting 3 dB from field strengths predicted by the method.



Ground distance, d, (km)

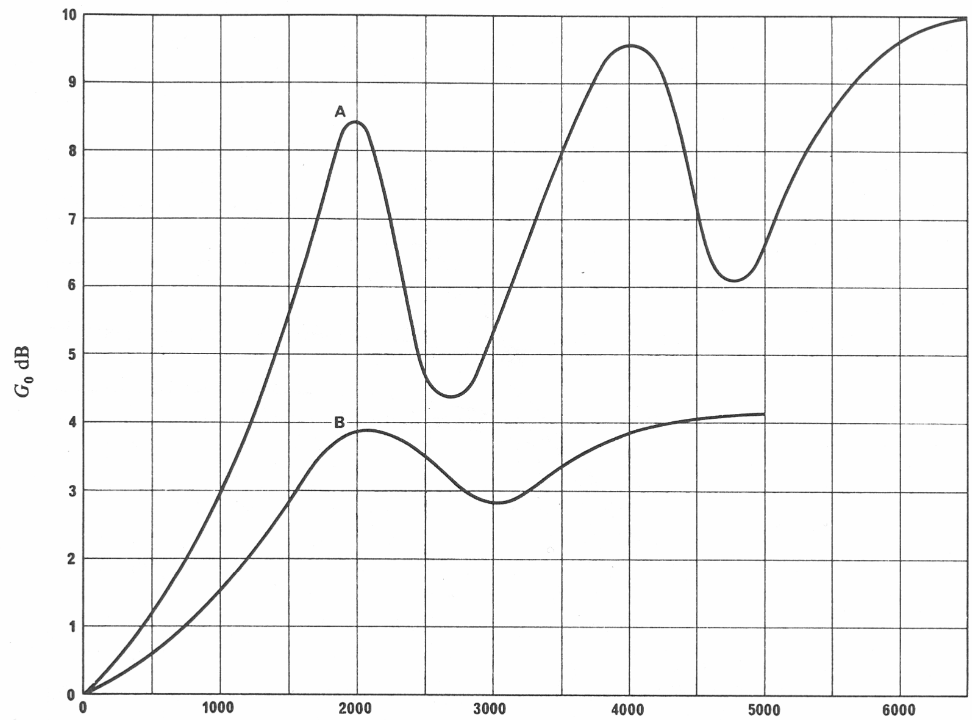
FIGURE 6

Transmitting antenna gain factor (G_V)

h = Antenna height

——— h_r = 100 km (E layer reflection)

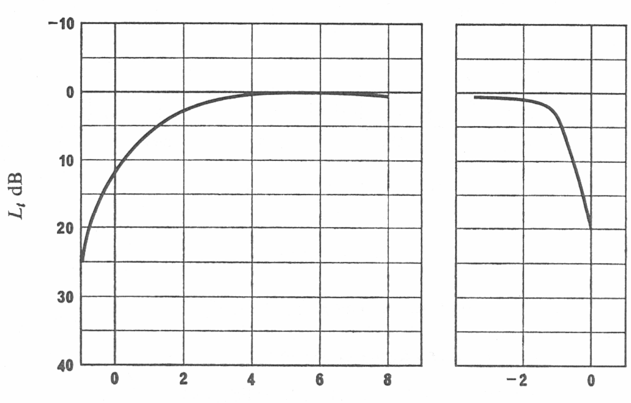
- - - - - h_r = 220 km (F layer reflection)



Ground distance, *d*, (km)
A: Band 6 B: Band 5

FIGURE 7

Sea gain (G_0) for a single terminal on the coast



Time after sunset (hours) Time after sunrise (hours)

FIGURE 8

Diurnal loss factor (L_t)

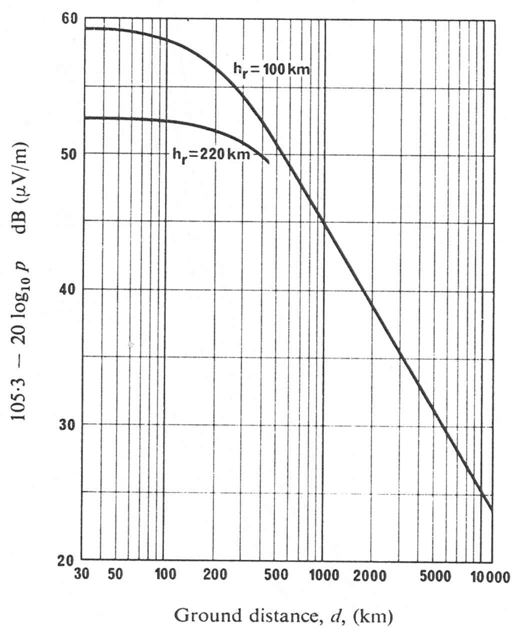


FIGURE 9

Basic field strength

The curves show $105{\cdot}3 - 20 \log_{10} p$

where $p = (d^2 + 4h_r^2)^{1/2}$

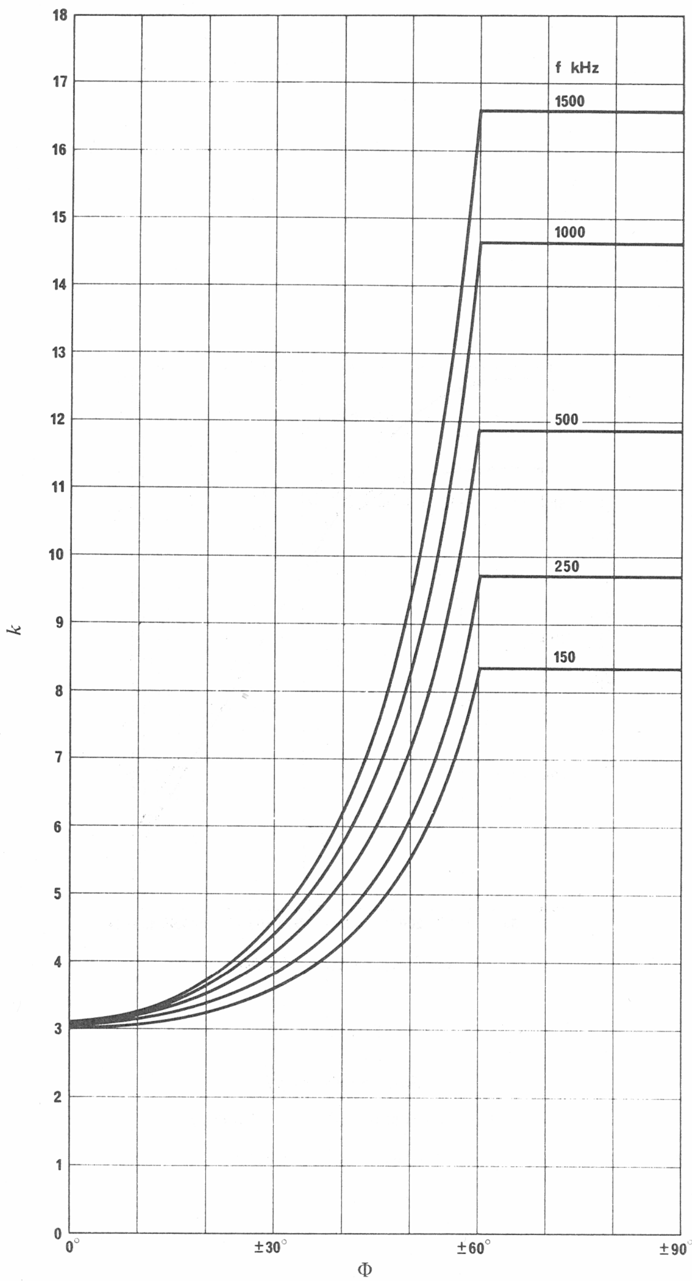


FIGURE 10

Basic loss factor k

$$k = 1{\cdot}9f^{0{\cdot}15} + 0{\cdot}24f^{0{\cdot}4}\,(\tan^2 \Phi - \tan^2 37°)$$

$$(0 \leqslant \Phi \leqslant 60°)$$

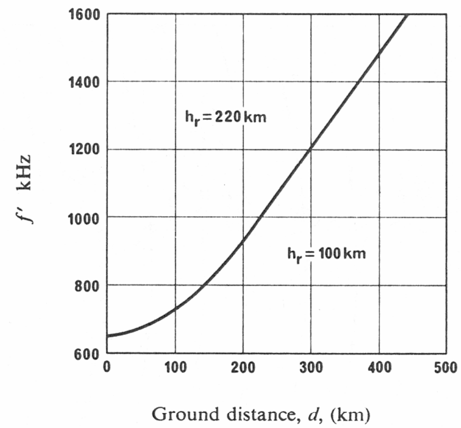


FIGURE 11

Frequency defined in equation (6)

$$f' = 350 + [(2{\cdot}8d)^3 + 300^3]^{1/3}$$

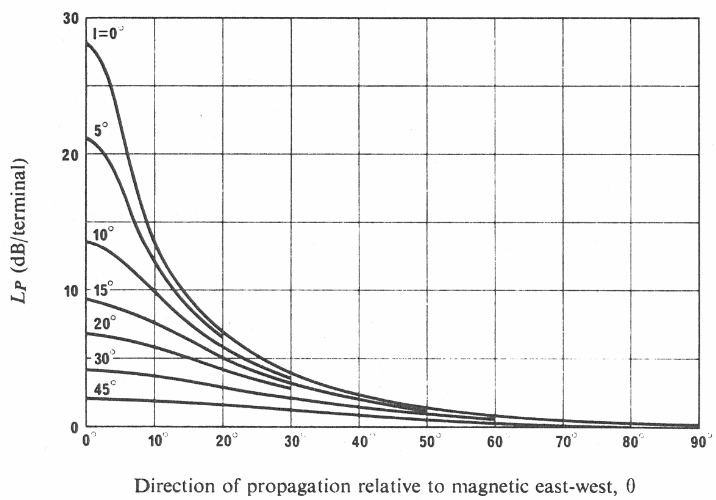


FIGURE 12

Excess polarization coupling loss L_P

$$L_P = 180\,(36 + \theta^2 + I^2)^{-1/2} - 2$$

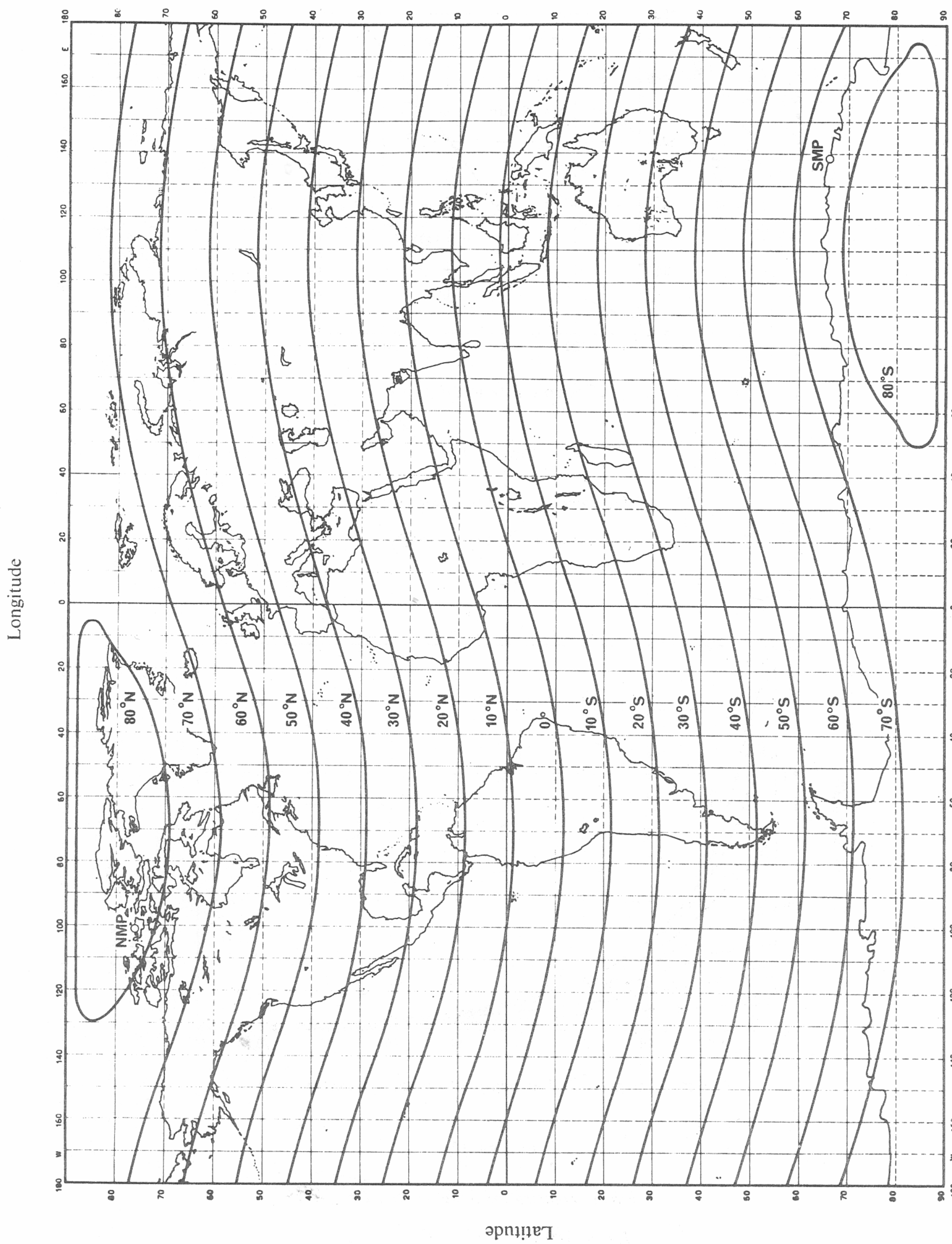


FIGURE 13

Geomagnetic latitudes

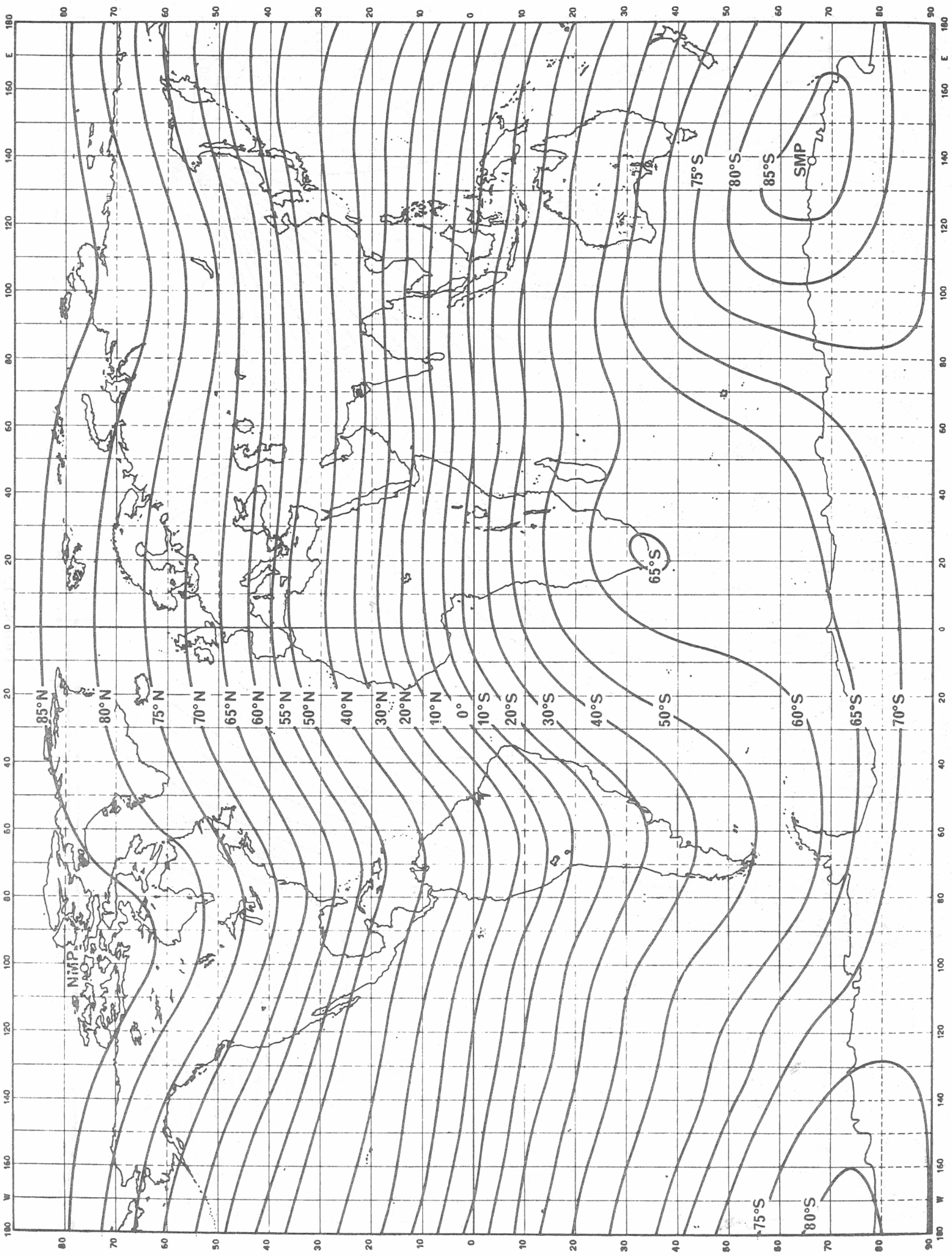


FIGURE 14

Map of magnetic dip

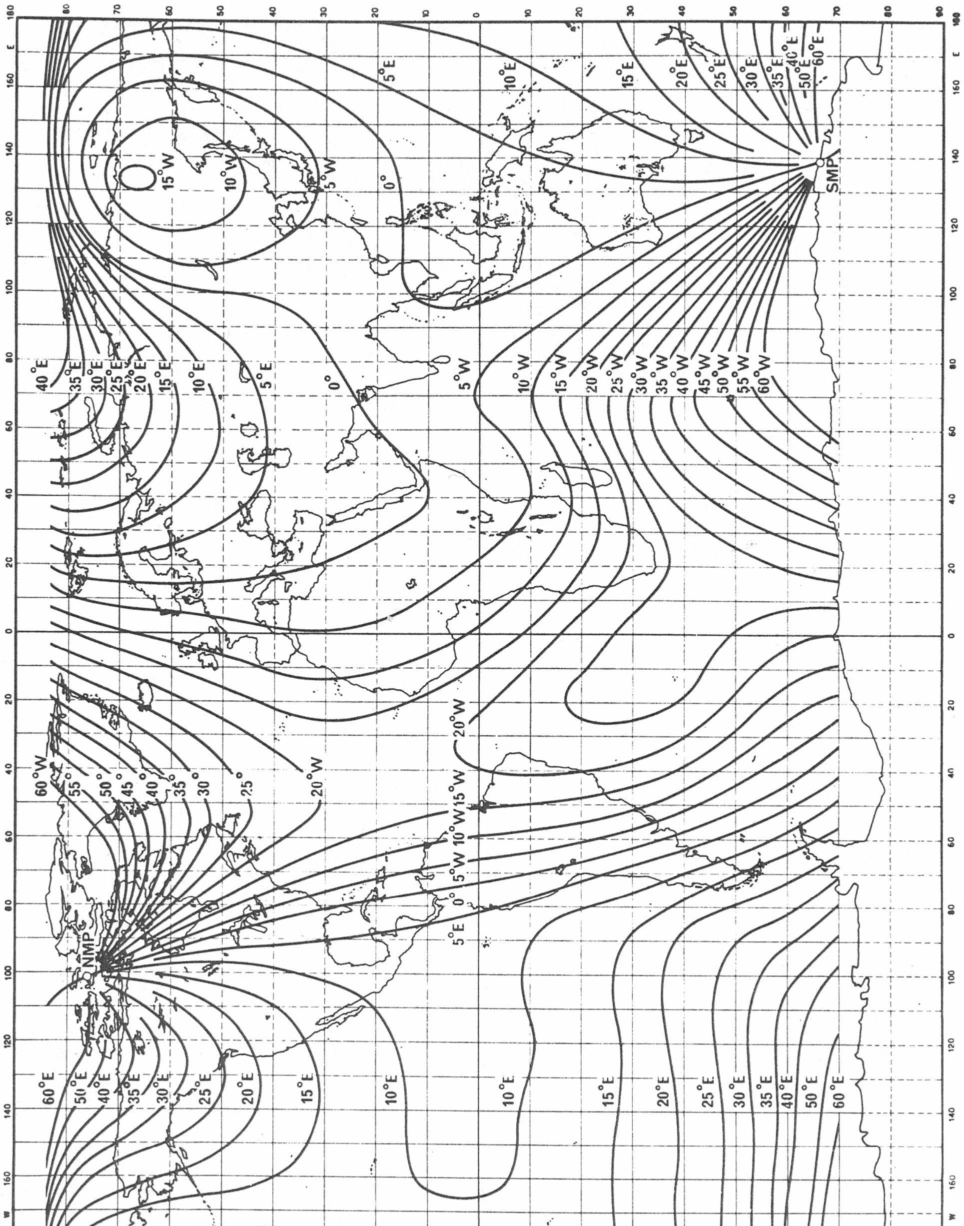


FIGURE 15

Map of magnetic declination (dotted curves east declination, continuous curves west declination)