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AN ULTRA-LOW FREQUENCY ELECTROMAGNETIC WAVE FORCE MECHANISM FOR THE IONOSPHERE

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ABSTRACT

Present theoretical explanations of the ionospheric behavior encounter certain difficulties in accounting for observed geographic, diurnal, and seasonal anomalies. Section II discusses, in particular, the two nocturnal maximum electron density concentrations which occur approximately 12 degrees above and below the geomagnetic equator, their seasonal variation and the sudden height increases, which occur in the F2 layer soon after twilight. In Section III a theoretical force mechanism for ionospheric matter, originated by J. M. Boyer, is briefly described. Such a model uses a mechanical potential geometry derived from electromagnetic standing waves generated by Mie scattering of ultra-low frequency energy from the sun incident on the earth. The importance of the $1/\omega^2$ dependence of the time average Lorentz force on charged matter within such a standing wave gradient is emphasized, weighing first order effects toward the first few dipole/multipole resonances of the earth in the region 7.0 to 70.0 cps. Some computer results for plane wave scattering from the earth in the above spectral region are displayed to show that the result is the erection of a complex wave geometry of three-dimensional potential wells for charged matter. Anomalies in the standing electromagnetic wave field are found to correspond well with observed ionosphere anomalies in the F2 region, when translation between the wave coordinate frame and the geographic frame is made.

* Principal Investigator, Northrop Space Laboratories, under NASA contract NAS-11138.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM X-53147

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SUMMARY

Present theoretical explanations of the ionospheric behavior encounter certain difficulties in accounting for observed geographic, diurnal, and seasonal anomalies. Section II discusses, in particular, the two nocturnal maximum electron density concentrations which occur approximately 12 degrees above and below the geomagnetic equator, their seasonal variation and the sudden height increases which occur in the F2 layer soon after twilight. In Section III a theoretical force mechanism for ionospheric matter, originated by J. M. Boyer, is briefly described. Such a model uses a mechanical potential geometry derived from electromagnetic standing waves generated by Mie scattering of ultra-low frequency energy from the sun incident on the earth. The importance of the $1/\omega^2$ dependence of the time average Lorentz force on charged matter within such a standing wave gradient is emphasized, weighing first order effects toward the first few dipole/multipole resonances of the earth in the region 7.0 to 70.0 cps. Some computer results for plane wave scattering from the earth in the above spectral region are displayed to show that the result is the erection of a complex wave geometry of three-dimensional potential wells for charged matter. Anomalies in the standing electromagnetic wave field are found to correspond well with observed ionosphere anomalies in the F2 region, when translation between the wave coordinate frame and the geographic frame is made.

I. INTRODUCTION

Various theoretical models have been used to explain the behavior of that ionized portion of the upper atmosphere known as the ionosphere. The following theory is not intended as a replacement for the accepted theories, but rather as a mechanism to explain many of the driving and controlling forces involved. If we accept the existence of electromagnetic fields resulting from standing waves, we must realize that these fields will exert an influence upon the charged matter present in the immediate vicinity. The solutions for the near-zone electromagnetic field, scattered from a perfectly conducting sphere, reveal force fields which may be used to account for various anomalous regions of the ionosphere when applied to the earth. In the following sections we will discuss some preliminary results obtained from a recent study.

II. DISCUSSION OF THE OBSERVED DATA

The earth is encompassed in a mass of gaseous matter, which we know as the earth's atmosphere. The atmosphere near the surface of the earth has been studied and is at least partially understood by meteorologists. At high altitudes, however, this situation is quite different. Until recently the earth's upper atmosphere was a completely abstract entity, not subject to any kind of study. In the latter part of the nineteenth century, Balfour Stewart hypothesized the existence of the ionosphere, and with the advent of radio the existence of this atmospheric region was confirmed. We now know that the ionosphere results from the ionization of atmospheric particles by solar high energy electromagnetic radiation and that radio waves are reflected mainly by the resulting electrons.

One might initially assume the ionosphere to be a symmetrical cover of ions and electrons over the earth's surface, with perhaps the number density being less on the night side than on the day side. Unfortunately, this picture is not nearly adequate as a representation of the actual state of the ionosphere. We must also consider the effects of the earth's magnetic field on the charged particles, and their interactions. The combination of these factors more nearly explains the observed behavior of the ionosphere; however, there still remain large discrepancies between the observed behavior and present theories.

The investigation of these problems is centered on the peak of the F2 layer (that point ascending along a perpendicular to the earth's surface at which the electron density is greatest). The diurnal variations in height and electron density may be examined by studying the recent IGY data. Figure 1 is a graphical representation of the electron density at the peak of the F2 layer. The electron density is measured by reflecting radio waves off the ionosphere. This reflection is governed by the following equation:

$$\mu = 1 - \frac{4\pi N e_e^2}{\epsilon_o m_e \omega^2}$$

where

μ = refractive index of the medium

ω = angular frequency of the wave

N = number density of electrons

m_e = mass of an electron

e_e = charge on an electron

ϵ_o = permittivity of free space

At the point where the radio wave is reflected, $\mu = 0$, the equations can be solved for N in terms of f, the wave frequency in megacycles per second, with the following result:

$$N = 1.24 \times 10^4 f^2.$$

In Figure 1 the contours which are related to the electron number density by the preceding equations are of constant frequency, f. Of main interest are the electron density increases which occur after nightfall at about ±12 degrees from the geomagnetic equator.

Figure 2 is the corresponding contour chart of constant height of the F2 peak. This map was arranged in a manner similar to the frequency chart. The average height of the maximum electron density for March 1958 is plotted for several stations which lie approximately along the 80°W meridian.

The height contours show very clearly the anomalous region which occurs just after nightfall at the geomagnetic equator. The sudden rapid increase in height of the F2 peak is not easily explained in terms of modern theories.

These anomalous regions may be explained by means of the Boyer Theory which hypothesizes the existence of force fields resulting from standing waves brought about by scattering of ultra-low frequency electromagnetic waves originating within the sun and propagating to the earth.

Solutions to the field components have been derived and preliminary results are discussed in the following section.

III. THEORETICAL MODEL AND DISCUSSION OF COMPUTED RESULTS

In this section a theoretical model, employed to examine the possibility that an electromagnetic wave force mechanism is at work in the earth's atmosphere, is outlined, and a few key results recently obtained from machine computations related to such a model are presented.

The cardinal premise of the electromagnetic wave force theory [1] is that stars, including our sun, radiate extremely low frequency radio waves whose energy spectra depart completely from the black body laws observed to obtain in the optical portions of the star's spectrum. Instead, a star is viewed as consisting of a matter sphere of complex dielectric constant excited internally by a thermonuclear source. Such a body is found to respond like a dielectric cavity to such internal excitation, producing internal standing waves, or resonances, at certain frequencies whose energy is forbidden to appear in the outside universe as well as anti-modes to which the stellar matter acts as a sort of impedance transformer effecting efficient transfer of internal energy to the outside. Thus, the emission spectrum is somewhat analogous in appearance to the energy states of the hydrogen atom, the lowest permitted lines being far apart but moving closer together in the spectrum with increasing frequency so that, in the optical or high frequency limit, we find a continuum or Planck-like region (Figure 3).

At a mean distance of some 93 million miles, such solar waves would be virtually plane. The consequences due to the incidence of such waves on the earth over a frequency band extending from 7.0 to 70.0 cycles per second were investigated by means of the mathematical edifice erected by Gustav Mie [8] in 1908. The frequency region noted was selected because it falls within the primary electromagnetic resonances of a sphere the size of the earth (Figure 4). Both the dipole and back-scatter resonances fall slightly lower in the audio-frequency spectrum than the Schumann resonances of the earth - ionosphere cavity elucidated by Wait [9] of the National Bureau of Standards and others.

Machine solutions were obtained for the total standing wave field generated by scattering and wave interference which would exist in the near and intermediate zone region surrounding the earth, extending from the surface to a distance of 11.5 earth radii. The influence of such a nonuniform, electromagnetic standing wave field on charged matter is inspected by means of the Lorentz force. If we consider only the time average force on charged matter, we derive the relation

$$\langle m \dot{\bar{v}} \rangle = -\frac{1}{4}\frac{q^2}{m\,\omega^2}\nabla(\bar{E}\cdot\bar{E}^*).$$

This result greatly simplifies the problem in that we may deal in all subsequent manipulation with a scalar mechanical potential obtained by dotting the total vector field into its complex conjugate. The $1/\omega^2$ term gives a matter wave force inversely proportional to the square of the angular frequency as well as the gradient of the scalar potential. Furthermore, we should emphasize that the total scattering cross section, and therefore, the absolute magnitude of $\bar{E}$ for a sphere within the Mie region is not constant, but oscillates in magnitude about the resonances. This fact removes arbitrariness from the problem and uniquely relates the total field in the scattering process to the dimensions and matter composition of a given astronomical body. Finally, the $1/\omega^2$ dependence of the force permits us to consider only the lowest order eigenvalues for a given body as of first order importance when studying the wave effects on matter in such an environment. The total field solutions obtained for the sphere are exceedingly difficult to present in a picture without resorting to plane cuts. Figure 5 shows a two-dimensional standing wave model which displays well the "mountain" and "valley" structure which results in space. This early plaster model for the total field around a wave scattering cylinder was constructed from data computed by Dr. Ronald P. King and Dr. Tsi Wu of Harvard [5]. These standing wave fields are stationary in position, but oscillate in amplitude at the angular frequency.

Now, if charged matter is present - generated say within a planetary atmosphere by incident high energy ultraviolet photons, or farther out by neutron albedo, or even farther still by injection of raw space matter - these charges tend to be guided by the gradient of such a field. After sufficiently long periods of time, charges will flow within the minimums or valleys of this wave geometry and may even collect in pools or potential wells erected at certain points in space by the standing waves.

Under a NASA contract grant (Reference 3 for final report) numerical solutions for the earth scattering sphere illuminated by solar electromagnetic waves in the frequency range specified were obtained. As a charged particle is influenced by all fields present in its vicinity, the total scalar potential - summed over the spectrum - was secured from the IBM 7094 computer as a function of radial distance, r, and the spherical directions $\emptyset$, θ.

In Figure 6, one sees the nonuniform scalar potential profile for an altitude of 1.050 earth radii (well into the F2 layer) for the ecliptic plane. If we take the gradient of such a potential around the earth in this plane we find a potential minimum existing about 70 degrees from ecliptic midnight or the anti-solar point. Taking into account the changing attitude of the earth's geographic and geomagnetic coordinate frames with respect to the ecliptic plane with the seasons, this calculated position for the field minimum agrees quite satisfactorily with that for the "twilight increase" observed in the F2 layer. The reason for the increase in height of a matter layer is seen in a plot of the calculated earthward pointing radial force component (Figure 7), which is weakest over the potential well. This radial force component then increases as we move toward midnight or ecliptic moon. Such a combination of force components also predicts a charge population decrease at the same region.

Figure 8 depicts an interesting feature in the potential computed for the plane normal to the ecliptic and along the earth-sun axis. A maximum or "bulge" occurs on the dark side away from the sun, falling within the auroral zone of the earth. The electromagnetic field here is found to be almost entirely composed of the radial electric component; the tangential component becomes significant only at a distance of about 7 earth radii.

Because of the position of the polar field bulge, it will describe one rotation in the auroral zone in one earth year. The calculated oscillating radial electric field lines and those of the static magnetic field of the earth lie closely parallel in this region (Figure 9), but the angular relationship does vary over the year with a repeat alignment occurring at the two equinoxes. This field geometry predicts the existence of an acceleration mechanism for electrons in the bulge zone with very little $\bar{v} \times \bar{B}$ interaction. Precisely such an electric mechanism for electrons was sought for in nature by J. W. Chamberlain [6] in his theoretical work of 1956 related to the long, thin ray aurora. Also, it was in altitudes above 50 km in the latitude zone occupied by the calculated field bulge that Van Allen and Kasper found soft X-ray activity [7] which could be plausibly ascribed to bremsstrahlung from accelerated primary electrons. As there exist in geophysics theoretical mechanisms which relate ionospheric storms to injection of ionizing particles in the auroral zone, this feature is pertinent to the work carried out in the grant study.

The latitude dependence of electron densities in the F2 layer may also be considered. Unfortunately, we have not yet secured sufficient field data in regions outside the three principal planes of the sphere to draw firm conclusions regarding this phenomenon. However, the polar plane force diagram (Figure 10), shows an abrupt reversal in direction of the radial force between the ecliptic plane and higher latitude. Figure 11 shows the same effect in the dawn-twilight polar plane, but at a slightly different latitude referenced to the ecliptic. There is no such reversal effect at all in the radial force in the ecliptic plane (Figure 12). Further study of these effects may lead to an understanding of the latitude dependence of the electron density.

Finally, the symmetry of the computed potential profiles above and below the ecliptic plane and about the axis between dawn and twilight (Figures 10-12) is artificial, being the result of considering only the earth in the wave-scattering problem. If we use the earth's first back-scattering resonance which has a wavelength of 6.28 earth radii or 25,000 miles, the moon is only 9.5 wavelengths distant from the earth. We therefore made a hand calculation for the moon in the accurately known position of the June 25, 1964, lunar eclipse to determine relative magnitudes of wave coupling which could exist between these bodies in the context of electromagnetic theory. Substantial coupling would exist and should vary markedly as a function of the position of the moon in its orbit. Such an effect would take place because of variation in the moon's bi-static scattering cross section and the changes in phase occasioned by change in distance from the earth due to the ellipticity of the lunar orbit.

In the test case calculated for a single point at an altitude of 318 km along the earth-sun line, variations in the earth field by as much as 75 percent and as little as 2 percent were found over the frequency band 7 to 70 cps, the average perturbation being about 20 percent. Although a complete machine computation for all positions of the earth-moon-sun triangle throughout the year must be run to determine the range of such wave coupling, considerations from antenna array theory tell us that the result will be a rotating distortion of the earth-alone field. This effect would destroy the calculated dawn-twilight profile symmetry and will influence the symmetry about the ecliptic plane because the moon's orbit is displaced from that plane. The wave mechanism described here predicts a lunar "tide" effect upon the earth's ionosphere by a force other than that of gravity, but again much work remains to be done before its importance can be estimated. Full details of the research reported here will be given in the final report on the research done under NASA Contract NAS8-11138.

III. CONCLUSIONS

The data presented here represent only a very preliminary computation effort leaving the main bulk of the work yet undone; however, it is felt that this preliminary work will lead to future studies which may very well open the way to an entirely new realm of space physics. If the ultra-low frequency electromagnetic waves actually exist - and there is much controversy over this point at this time - then the existence of these force fields cannot be denied. Earth-based experiments have measured fields which correspond in frequency to those which are postulated in the report. These fields are neither weak nor unpredictably variable, but rather are an ever-present and significant contribution from a previously undetermined origin.

Additional studies which should be undertaken in the process of verifying the Boyer theory are many and varied; however, the first course of action should be to continue the work under progress in determining the perturbing mechanisms. Such mechanisms involve the moon scattering and interference problems mentioned in Section III and the interrelation of the earth's geomagnetic field with the electromagnetic field.

A second study would be directed toward determining the diurnal, seasonal, and solar cycle variations of the electromagnetic field.

A third study would be directed toward determining the effects of these fields on the Van Allen radiation zones. The acceleration of particles within the radiation belts as well as the rapid "dumping" of these particles into the earth's atmosphere may possibly be explained by the forces exerted upon them by these electromagnetic fields.

A fourth study would be directed toward determining whether or not perturbations in these fields could be used as a warning system for solar flares. The waves which originate in the "solar cavity" may be perturbed to such an extent prior to the occurrence of large solar flares that these perturbations could be detected at the earth. The problem of an adequate solar flare warning system must be solved before extended duration missions can be launched into space with a high probability of success.

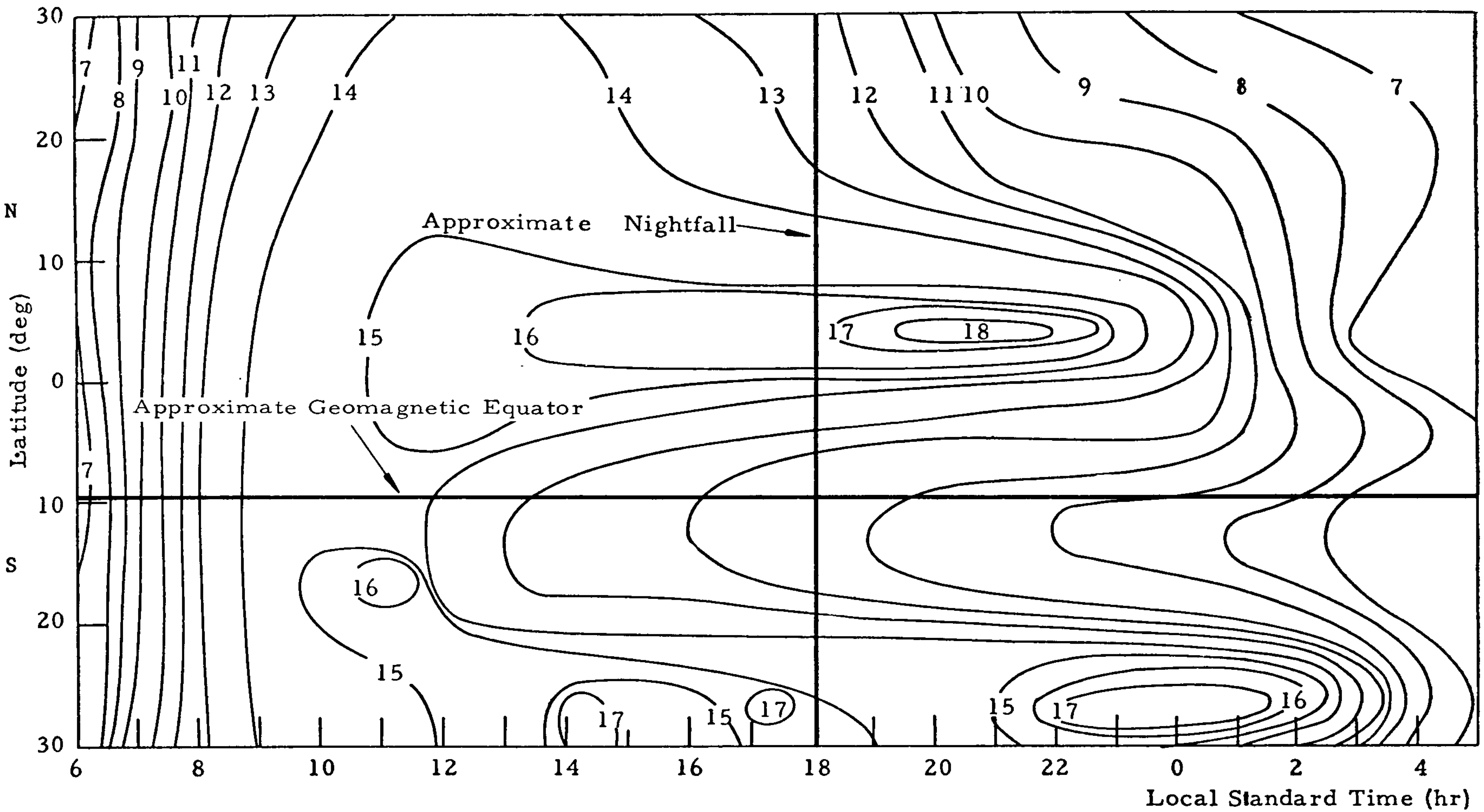


Figure 1. Contours of Constant Frequency (Mc/sec) for the Peak of the F_2 Layer Averaged over the Month of March 1958.

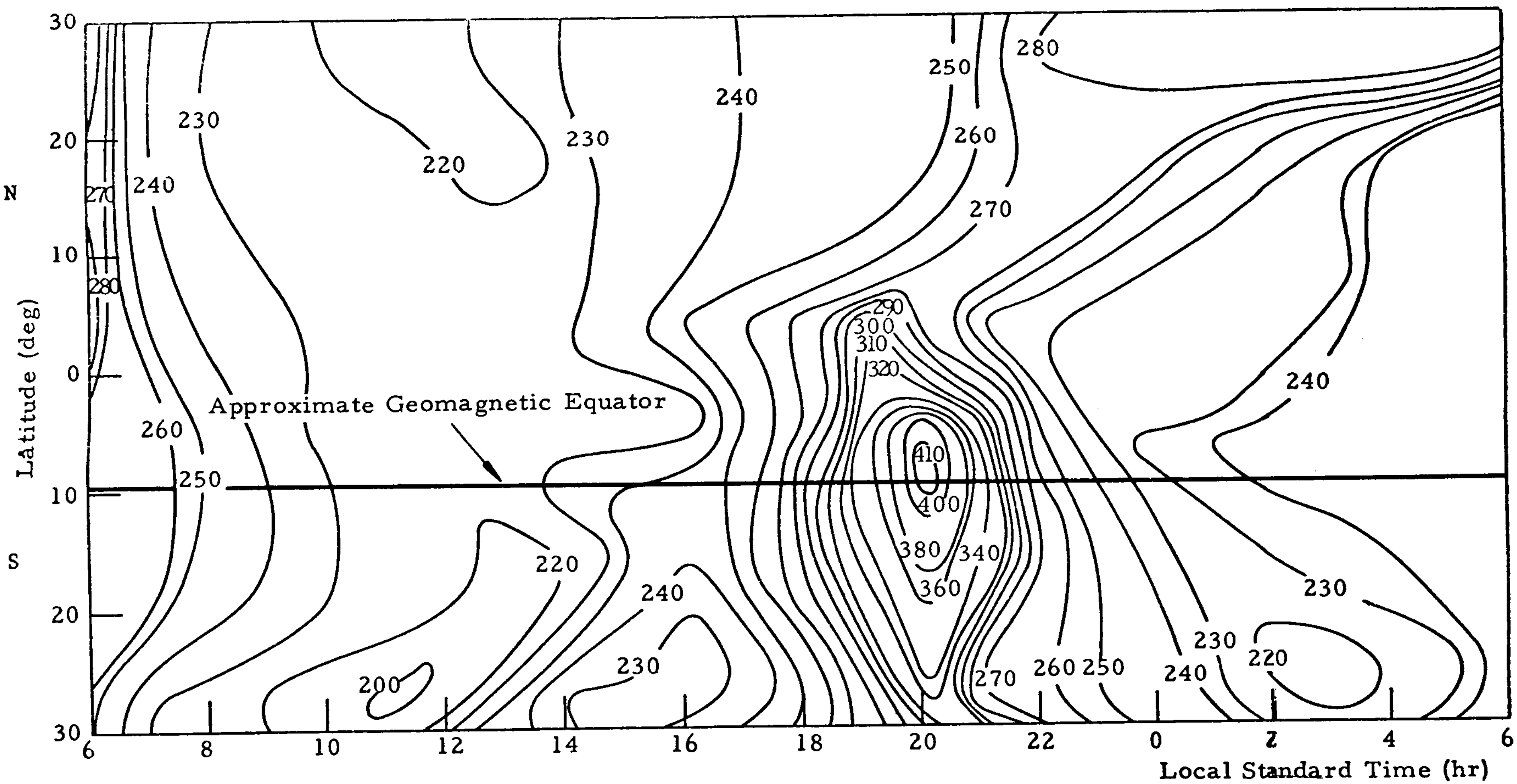


Figure 2. Contours of Constant Height (km) of the Peak of the F_2 Layer Averaged over the Month of March 1958.

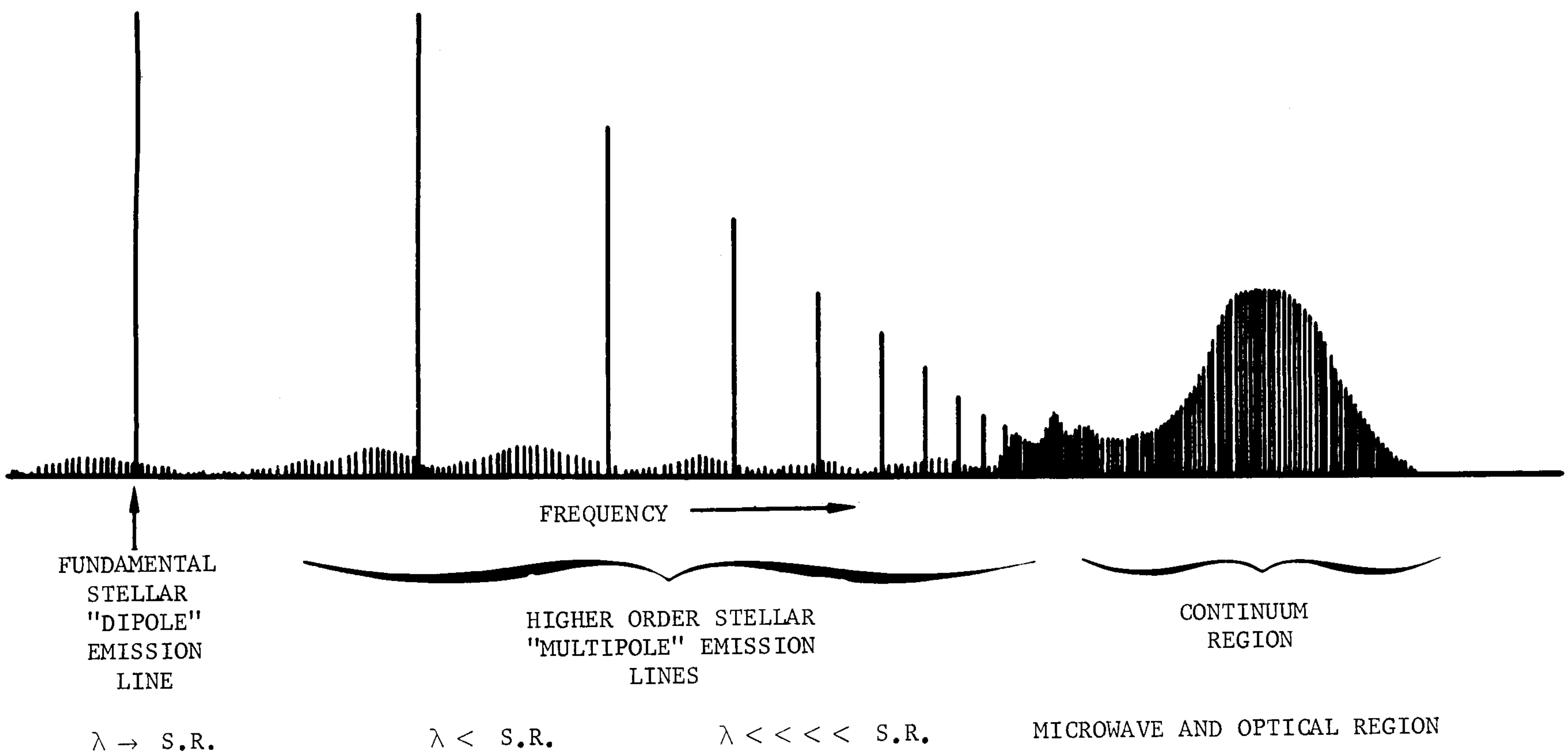


FIGURE 3. POSTULATED STELLAR RADIO EMISSIONS
(S.R. = Star Radius)

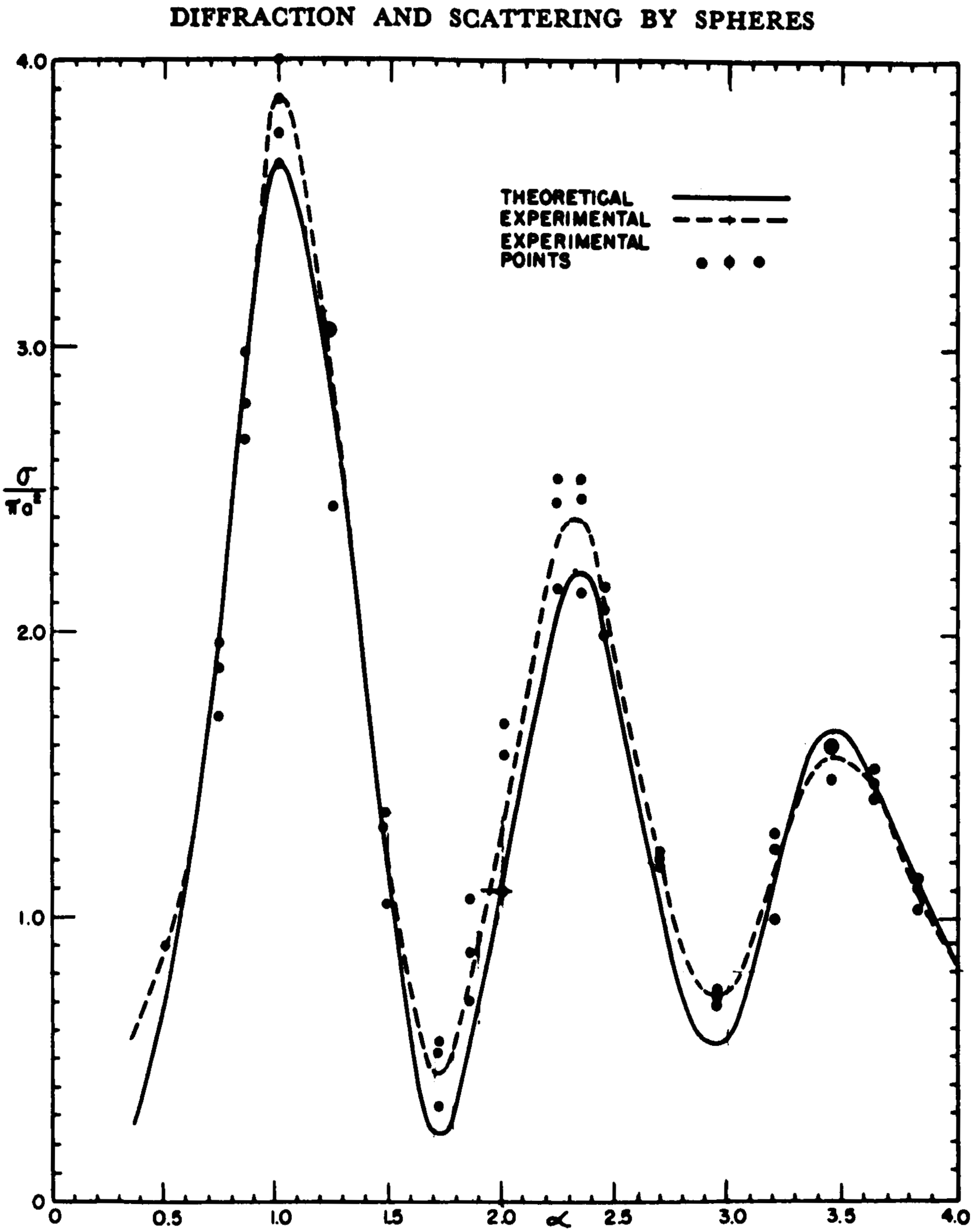


FIGURE 4. BACK-SCATTERING FROM METAL SPHERES (ADEN, REFERENCE 10)

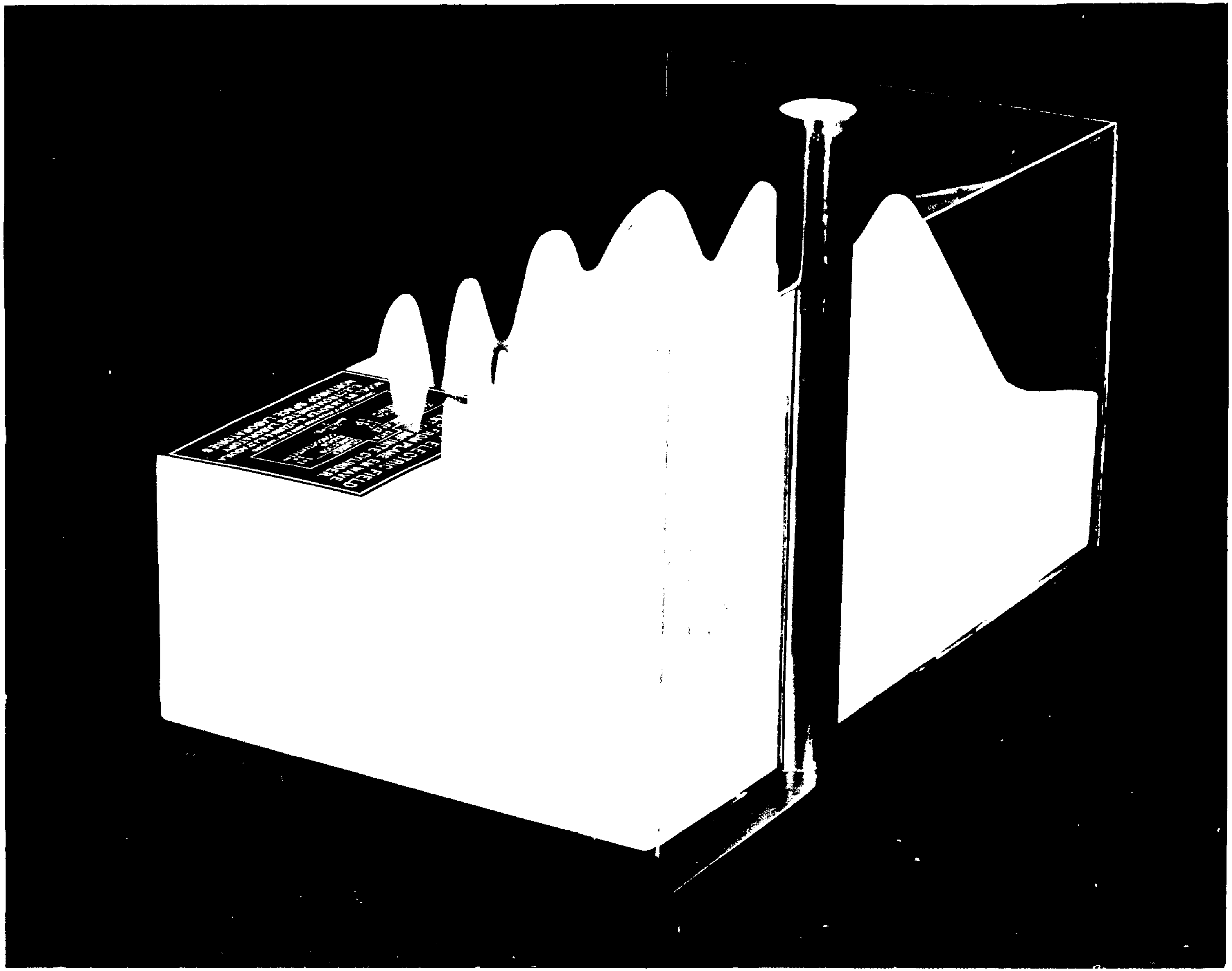


FIGURE 5. FIELD RESULTING FROM SCATTERING OF ELECTROMAGNETIC WAVES FROM AN INFINITELY LONG CYLINDER (KING AND WU)

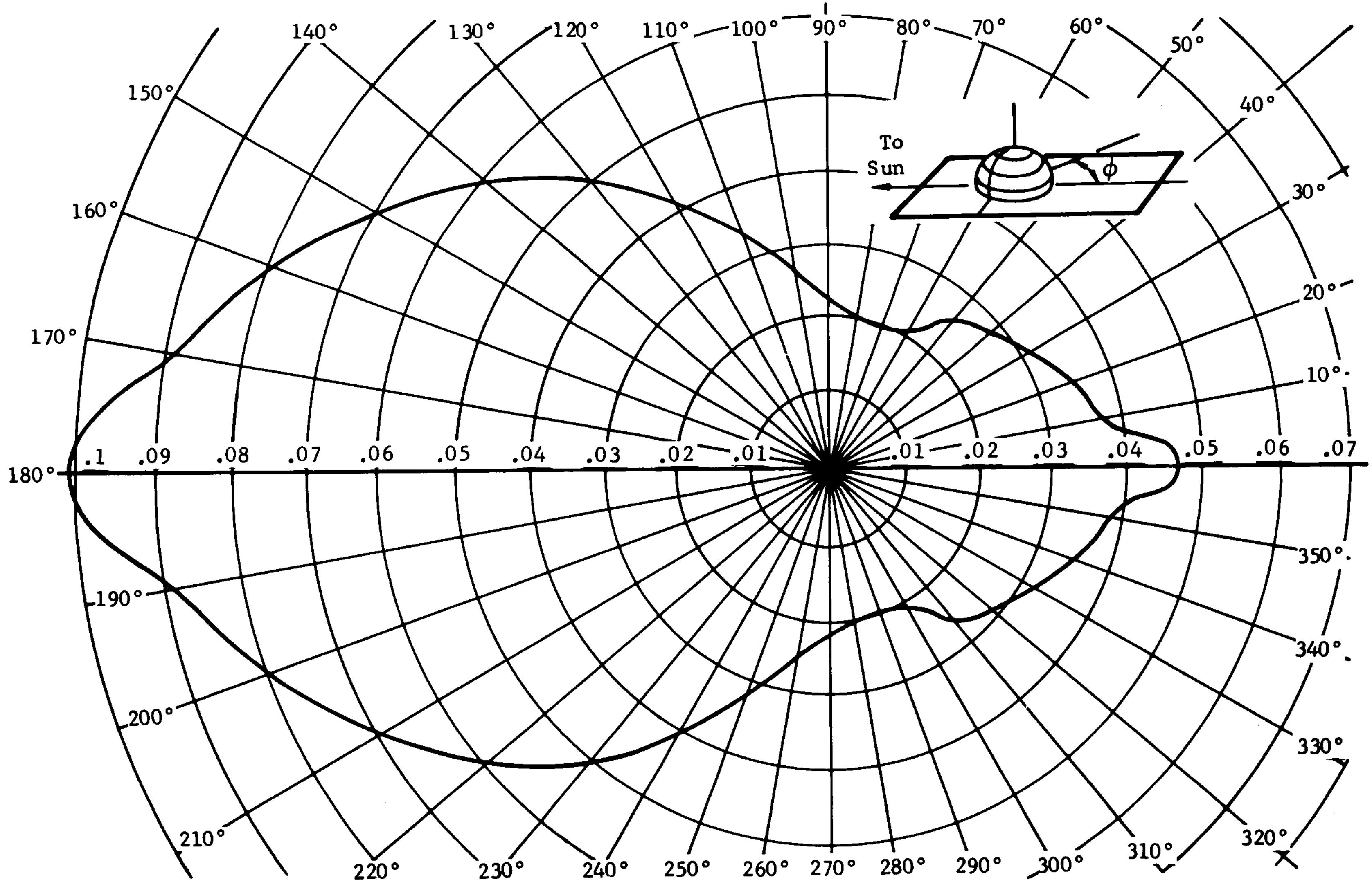
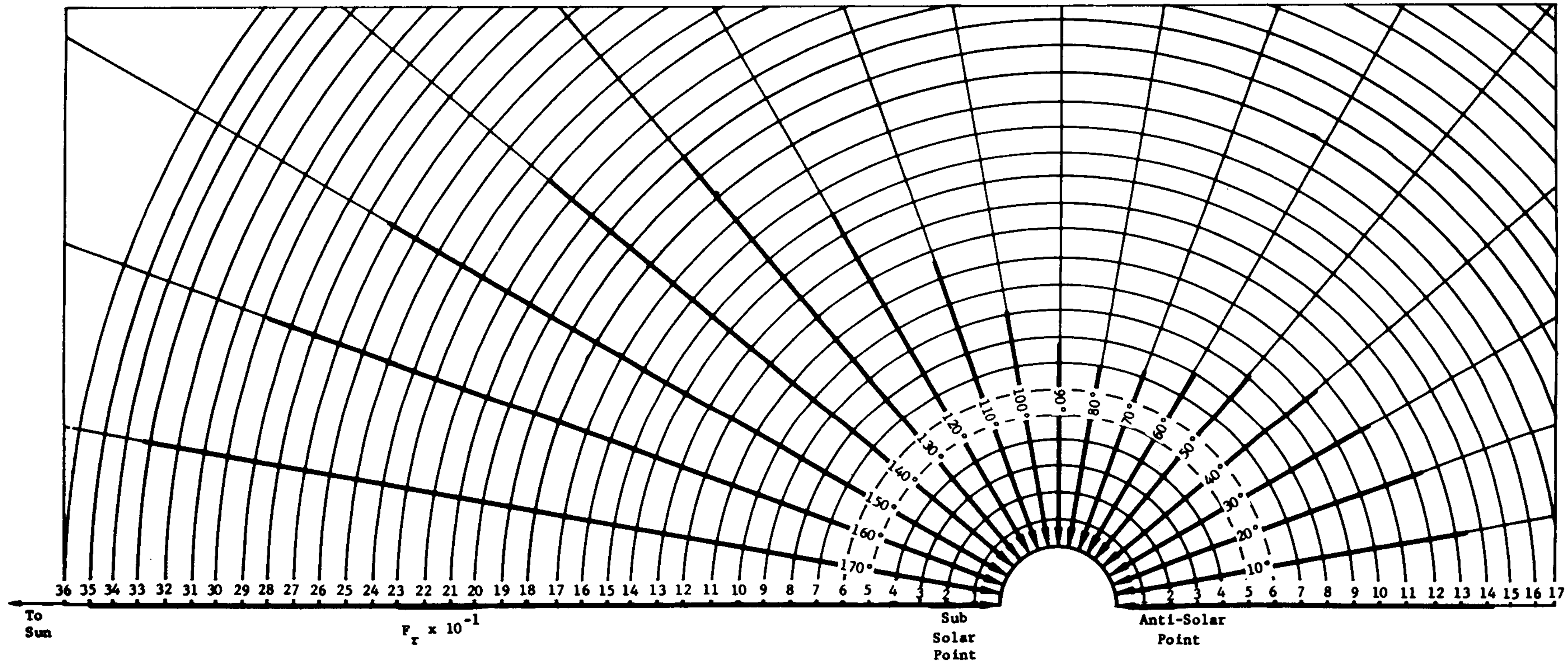


FIGURE 6 NORMALIZED SCALAR POTENTIAL $V_{mech.}$ IN THE PLANE $\theta = 90°$, $\phi = 0 - 360°$,

Showing Ecliptic Plane Potential "Well" at About 1900 Hours, S.M.T. (≅ 75° and 280°). Altitude 1.05 Re. Earth Only; No Contribution From Lunar Scattering Considered.



Although midnight-dawn-noon segment is shown, the noon-twilight-midnight segment is a mirror image of the figure. Earth only; no contribution from lunar scattering considered.

FIGURE 7. NORMALIZED RADIAL FORCE F_r COMPUTED BETWEEN 1.05 AND 1.055 Re, IN ECLIPTIC "PLANE" $\theta = 90°$, $\emptyset = 0° - 180°$

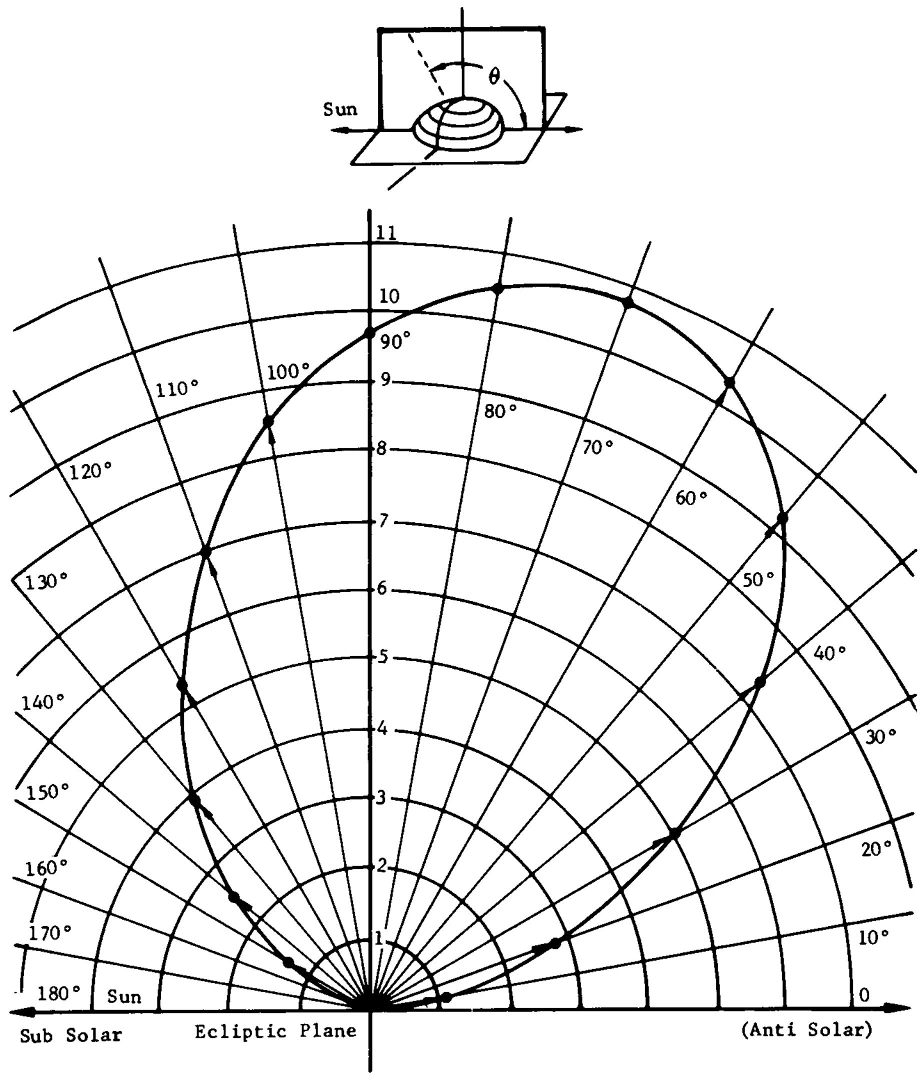


FIGURE 8 NORMALIZED SCALAR POTENTIAL V_{mech} IN THE PLANE $\phi = 0°$, $\theta = 0° - 180°$

Showing the "Auroral Bulge". (Altitude of 1.05 Re.) Lower Half Below Ecliptic Plane is Mirror Image of Figure. Earth Only; No Contribution from Lunar Scattering Considered.

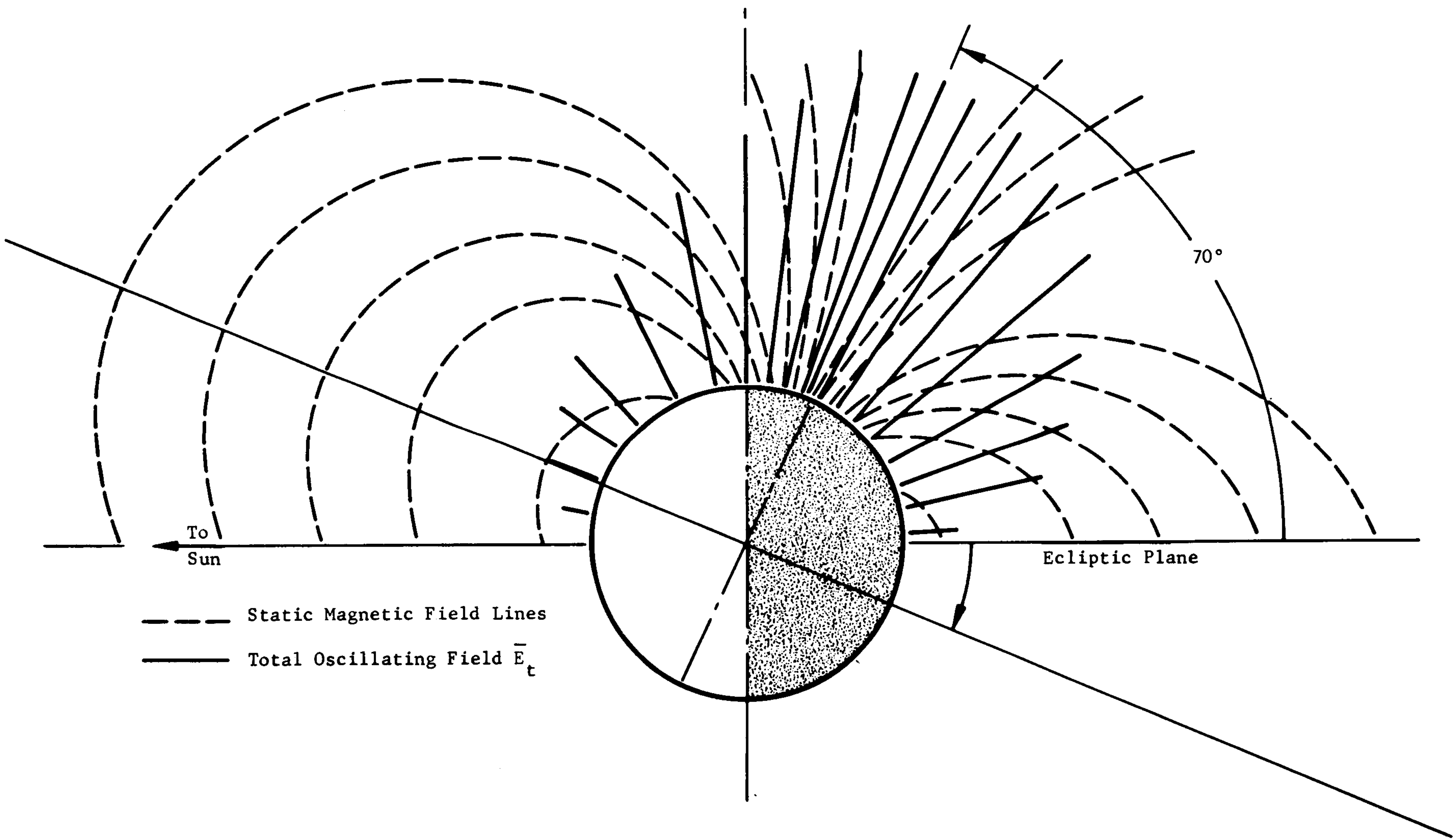
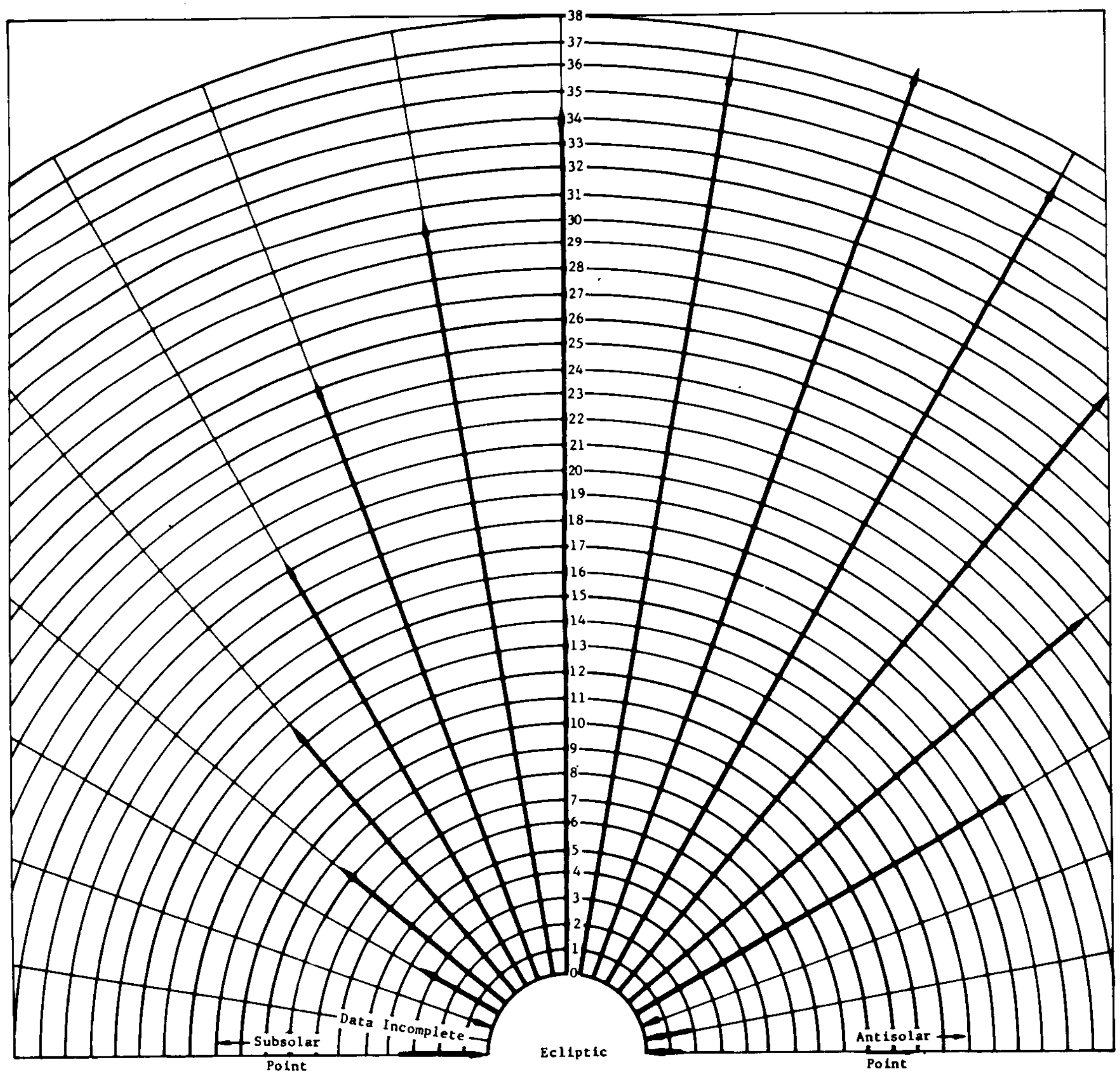
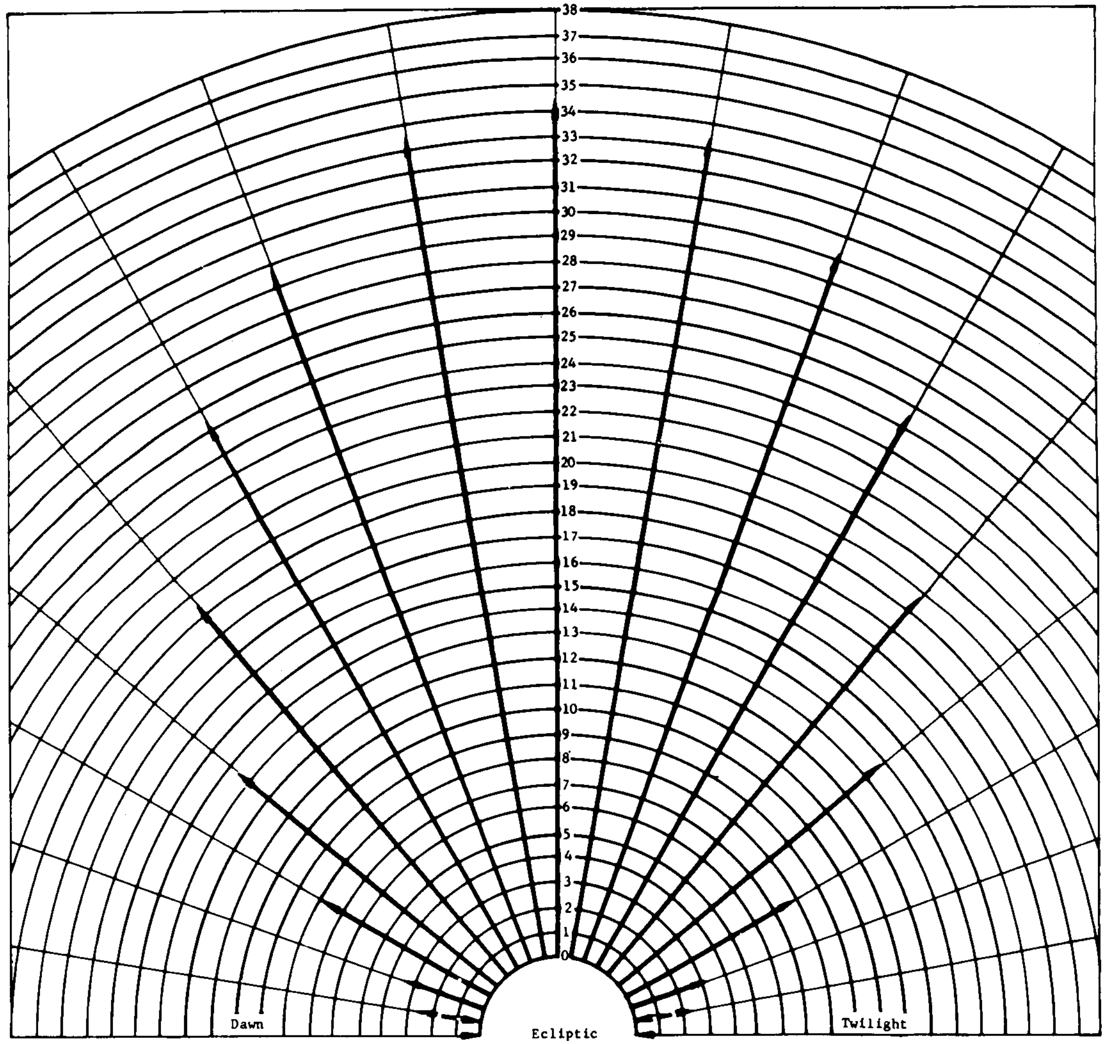


FIGURE 9. COMPARISON OF THE EARTH'S GEOMAGNETIC FIELD TO THE SCATTERED ELECTROMAGNETIC FIELD



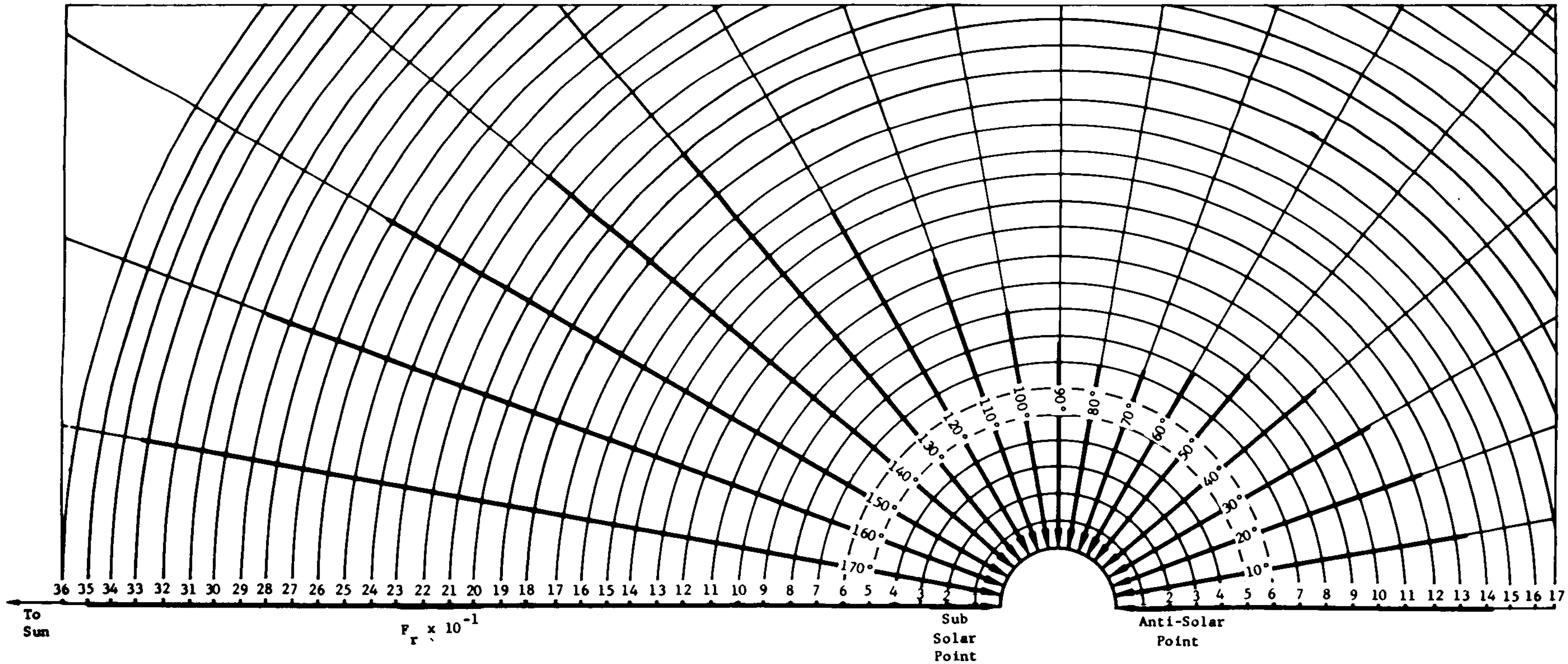
Plane of Cut $\phi = 0°$, $\theta = 0° - 180°$. Lower Half Below Ecliptic Plane is Mirror Image of Figure. Earth Only; No Contribution From Lunar Scattering Considered.

FIGURE 10. NORMALIZED RADIAL FORCE $\bar{F}_r$ COMPUTED BETWEEN 1.05 AND 1.055 Re, SHOWING REVERSAL OF FORCE SIGN IN LOW ECLIPTIC LATITUDE



Dashed Line at 20° Above Ecliptic Plane Denotes Sensitivity of Force Sign at this Latitude To Radial Distance [$F_r \sim 0$ at 1.07 Re, Changing Sign and Increasing at Greater Re] . Plane of Cut $\phi = 90°$, $\phi = 0 - 90°$. Lower Half Below Ecliptic Plane is Mirror Image of Figure. Earth only; No Contribution from Lunar Scattering Considered.

FIGURE 11. NORMALIZED RADIAL FORCE $\bar{F}_r$ COMPUTED BETWEEN 1.05 AND 1.055 Re SHOWING REVERSAL OF FORCE SIGN IN LOW ECLIPTIC LATITUDE



Although Midnight-Dawn-Noon Segment is Shown, The Noon-Twilight-Midnight Segment is a Mirror Image of the Figure. Earth Only; No Contribution From Lunar Scattering Considered.

FIGURE 12. NORMALIZED RADIAL FORCE F_r COMPUTED BETWEEN 1.05 AND 1.055 Re, IN ECLIPTIC "PLANE" $\theta = 90°$, $\emptyset = 0 - 180°$

REFERENCES

1. Boyer, J. M.,"A Radio Wave Mechanism to Account for the Radial Distribution of Known Van Allen Belts about the Earth," IAS Paper #92, January 1962.

2. Maldonado, C. D., "Forces on a Particle in a Non-Homogeneous Electromagnetic Field Established by Mie Scattering from a Conducting Earth," NSL Technical Memorandum NSL 64-100, Northrop Space Laboratories, March 1964.

3. Boyer, J. M., J. R. Coleman, and C. D. Maldonado, "Investigations on the Future Development and Verification of the Boyer Theory," Northrop Space Laboratories, Report Number NSL 64-188, September 1964.

4. Roberts, W. T.,"Properties of the F2 Region of the Ionosphere," NASA, MTP-AERO-63-23, April 15, 1963.

5. King, Ronald P. and T. T. Wu, "The Reflection of Electromagnetic Waves from Surfaces of Complex Shape," Scientific Report #13, Craft Laboratories, Harvard University, December 1957.

6. Chamberlain, J. W., Airglow and the Aurora, edited by E. Armstrong and A. Dalgarno, Pergamon Press, London, 1956.

7. Van Allen, J. A. and J. E. Kasper, Bulletin of the American Physical Society, Vol. 1, p. 230, 1956.

8. Mie, Gustav, Ann. Physik, Vol. 25, p. 377, 1908.

9. Wait, J. R., "Terrestrial Propagation of Very Low Frequency Radio Waves," Journal of Research, National Bureau of Standards - D-Radio Propagation Volume 64D No 2, March - April, 1960.

10. Aden, A. L., "Electromagnetic Scattering from Metal and Water Spheres," Technical Report No. 106, Craft Laboratories, Harvard University, August 1950.

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This document has also been reviewed and approved for technical accuracy.

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