



Recommendation ITU-R P.619-3
(12/2017)

**Propagation data required for the
evaluation of interference between
stations in space and those on the
surface of the Earth**

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Radiowave propagation



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Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

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RECOMMENDATION ITU-R P.619-3

Propagation data required for the evaluation of interference between stations in space and those on the surface of the Earth

(Question ITU-R 208/3)

(1986-1990-1992-06/2017-12/2017)

Scope

This Recommendation provides methods for predicting signal propagation losses for interfering signals between stations in space and stations on (or near to) the surface of the Earth in the overall frequency range of 100 MHz to 100 GHz, except for a few exceptions restricted to lower frequencies which will be specified where they are described. Prediction methods for some of the loss mechanisms are reliable over narrower frequency ranges, and some of the loss mechanisms are not significant at certain frequency ranges. This Recommendation provides methods to predict the propagation losses not exceeded for 0.001%-50% of the time. Guidance is given for single entry as well as multiple entry propagation losses in analyses that determine interfering signals, where correlations of temporal variability and location variability may be influential.

Keywords

Interference, depolarization, beam spreading, scintillation, diffraction, ducting

The ITU Radiocommunication Assembly,

considering

- a) that for the assessment of interference between stations based in space and those on the surface of the Earth, it is necessary to have propagation data and prediction methods that take account of atmospheric factors, and in some cases terrain, building penetration, multipath and clutter;
- b) that, given the many possible applications of such evaluation, guidance is required for the selection of appropriate methods;
- c) that certain analyses of potential or actual interference may need to determine the aggregate total interfering signal from numerous transmitters,

noting

- a) that Recommendation ITU-R P.526 provides calculation methods for obstacle diffraction;
- b) that Recommendation ITU-R P.531 provides propagation data and prediction methods for ionospheric effects on Earth-space paths;
- c) that Recommendation ITU-R P.618 provides guidance on the planning of Earth-space links;
- d) that Recommendation ITU-R P.676 provides methods for calculating attenuation by atmospheric gasses;
- e) that Recommendation ITU-R P.834 provides information and calculation methods for the effects of tropospheric refraction;
- f) that Recommendation ITU-R P.836 provides information and calculation methods for the water-vapour content of the atmosphere, including its temporal variability;
- g) that Recommendation ITU-R P.2040 provides information on the interaction of radio waves with buildings,

recommends

that the guidance in Annex 1 be used for the assessment of interference between stations based in space and those on the surface of the Earth.

Annex 1

1 Introduction

This Recommendation provides guidance and calculation methods to evaluate interference between a station in space and a station on the surface of the Earth. The phrase “on the surface of the Earth” is intended to cover antennas which are within the atmosphere and not at a great height above the surface, including those installed on radio towers, buildings, land vehicles, or hand-held. This Earth-based station may be part of a satellite or terrestrial radio system. For brevity, it is sometimes referred to as the “Earth-based station”.

The phrase “Earth-space” path refers to the path of radio energy between antennas in either the Earth-to-space or the space-to-Earth direction.

All propagation mechanisms are reciprocal with respect to direction unless stated otherwise.

1.1 Temporal and location variability

Many propagation losses vary in time, and with the location of Earth-based stations, particularly those located on the surface of the Earth.

Many interference analyses are “statistical” and need to consider potential temporal and spatial variabilities. If a complete cumulative distribution function of Earth-space basic transmission loss is needed, Recommendation ITU-R P.618 should be used for losses exceeded for percentages of time less than 50%. Attenuations and signal power enhancements caused by individual propagation mechanisms on an individual signal path may be treated as independent variables in many cases. Likewise, in analyses where carrier-to-(noise + interference) ratio is a figure-of-merit, interfering and desired signal power and depolarization effects may be treated as independent variables except for where the desired and interfering signal paths are physically near one another or overlapping and thus have a high degree of correlation.

For certain scenarios, there may be a degree of correlation among propagation losses on the interfering signal paths which can be accounted for by selection of the appropriate methods.

1.2 Apparent and free-space elevation angles

The elevation angle of the ray at an Earth-based station to a station in space is higher than it would be in the absence of any atmosphere, due to atmospheric refractivity. Account should be taken of this effect, particularly at low elevation angles.

The elevation angle which would exist in the absence of any atmosphere is referred as the “free-space” elevation angle, and has the symbol θ_0 . The actual angle of the radio path at the Earth-based station, including the effect of atmospheric refractivity, is referred to as the “apparent” elevation angle, and has the symbol θ .

Attachment B gives methods to convert between free-space and apparent elevation angles.

1.3 Relevant propagation mechanisms

The principal basic transmission loss mechanisms on interfering signal paths occur during clear-air conditions and may include in some cases, tropospheric and ionospheric scintillation, multipath, and mechanisms associated with signal path obstructions (clutter, diffraction over terrain, and building entry loss). Section 2 describes these mechanisms and gives calculation methods. Sub-sections 2.1 to 2.8 describe the mechanisms in detail. Section 3.1 gives the expression for basic transmission loss for a single specific path. Section 3.2 gives the expression for basic transmission loss for multiple sources into a single receiver.

Some evaluations of interference may need to take precipitation effects into account. The relevant mechanisms are described in § 3. Sub-sections 2.9 and 2.10 give information and calculation methods for interference caused by rain scattering, and differential rain attenuation, respectively.

These mechanisms are considered below and are applied to determine propagation losses that are not exceeded for 50% and smaller percentages of time that are of particular interest in interference analyses.

Section 4 discusses correlation between propagation mechanisms.

2 Propagation mechanisms

The following sub-sections summarise the mechanisms which in combination determine the attenuation between the (interfering) transmitter and (interfered-with) receiver antennas, with the associated symbols to be used in equations. This overall loss is expressed as basic transmission loss, which is the loss which would occur between ideal isotropic antennas.

2.1 Free space basic transmission loss L_{bfs} (dB)

This is the basic transmission loss assuming the complete radio path is in a vacuum with no obstruction. It depends only on the path length, d (km), and frequency, f (GHz) according to

$$L_{bfs} = 92.45 + 20 \log(f \cdot d) \quad (\text{dB}) \quad (1)$$

Attachment A gives a method for calculating the length of an Earth-space path, and the free-space elevation angle at the Earth-based station. It is based on spherical Earth geometry, and ignores the effect of atmospheric refraction. The associated errors are not significant for calculating free-space transmission loss from the path length. L_{bfs} must always be included in the calculation of loss over an Earth-space path. It is valid for any frequency and over any Earth-space path length.

Attachment B gives methods for converting between the free-space elevation angle and the apparent elevation angle at the Earth-based station.

The method in Attachment A takes no account of any obstruction by the Earth or objects upon it such as buildings. Attachment E gives a method for testing an Earth-space path for obstructions. Diffraction loss due to obstructions is discussed in § 2.6.

2.2 Depolarization attenuation A_{xp} (dB)

Two propagation mechanisms can cause the polarization angle of a radio signal to change:

- i) Faraday rotation;
- ii) Hydrometeor scattering.

Polarization mismatch may also be attributed to antenna mismatch without rotation due to propagation effects. This is not considered in this recommendation since it involves system considerations rather than propagation.

Depolarization effects can be caused either by Faraday rotation or by precipitation scatter. Faraday rotation is only significant below 10 GHz and can be ignored for frequencies at or above 10 GHz. Depolarization loss can be significant in reducing interference. For most multiple-entry Earth-space interference situations where relative polarization orientations can be considered arbitrary, $A_{xp} = 3$ (dB) assumes that the transmitter and receiver polarization vectors are in the same plane with a uniform distribution of relative angles. In practice the polarization vectors will be arbitrarily oriented in three-dimensional space which would combine to a higher aggregated loss. $A_{xp} = 3$ (dB) is thus unlikely to over-estimate the loss.

The polarization discrimination from a space-based interference source received by an earth-based station (or vice-versa) depends on the polarization purity of the transmitted wave, as well as the cross-polarization isolation of the receiving antenna. The depolarization loss can be directly calculated in terms of parameters that describe the interfering and receiving antennas' respective polarization types and polarization purities such as axial ratio in the case of circular polarization or linear cross-polarization isolation in the case of linear polarization. In addition, the polarization sense and tilt angle of the incident wave and the receiving antenna, will act to further reduce the net depolarization loss when the actual interfering and interfered-with system parameters are taken into account.

2.2.1 Cross-polar discrimination and cross polar attenuation

Polarization mismatch can occur for several reasons, and are sometimes quantified in terms of cross-polar discrimination (XPD) which is defined as the ratio of co-polar to cross-polar signal strength, normally expressed in decibels. It is a figure-of-merit where frequency sharing is implemented by orthogonal linear polarization.

Any degradation of XPD transfers a proportion of the power to the orthogonal polarization, which can constitute a source of interference. There is a corresponding attenuation of the original signal.

Cross- and co-polar attenuations are given by:

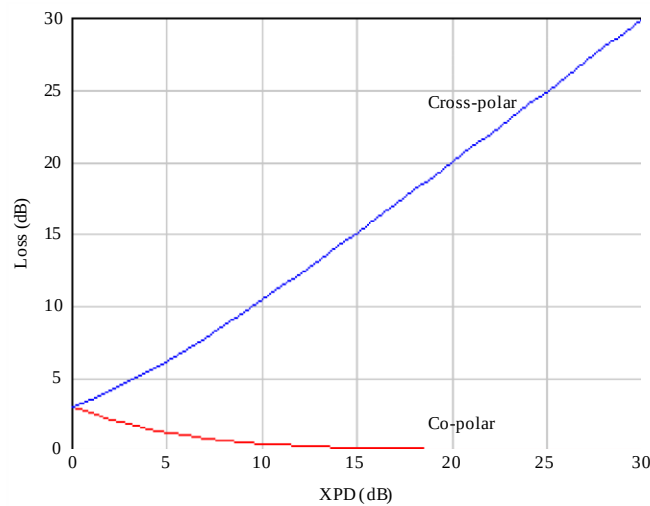
$$A_x = 10 \log(1 + 10^{0.1 R_{xpd}}) \quad (\text{dB}) \quad (2a)$$

$$A_c = 10 \log(1 + 10^{-0.1 R_{xpd}}) \quad (\text{dB}) \quad (2b)$$

where R_{xpd} is the XPD ratio in dB.

Figure 1 shows co-polar and cross-polar attenuation plotted against XPD.

FIGURE 1
Co- and cross-polar losses versus XPD



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Usually space borne RF systems employ signals with specified polarization depending on their functions. For instance tracking systems, air traffic control systems, and communication systems use vertically polarized signals to minimize interference due to reflection from ground surface.

Land surface remote sensing systems use horizontal polarization to ensure maximum coupling of the transmitted signals with ground surface. Those systems also use different polarizations to get auxiliary detail information. GNSS systems use circularly polarized signals to avoid impacts of Faraday rotation and to relax any restriction on the polarization direction of receiver antennas. Accordingly, it is important to assess values of RF signals with a specified polarization along a specified propagation path. Any reduction in those values can be considered a loss.

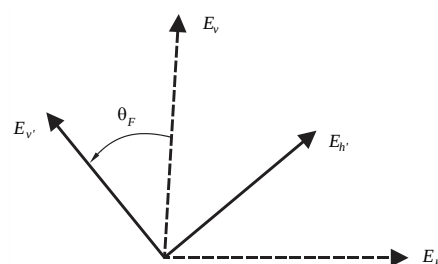
2.2.2 Faraday rotation

A linearly polarized field propagating through the ionosphere rotates from its initial direction by Faraday rotation angle θ_F . This means that the field can be split into two components:

- One component oriented along direction of initial polarization and having value proportional to $\cos \theta_F$;
- Another component orthogonal to the initial direction and having a value proportional to $\sin \theta_F$.

Figure 2 illustrates transmitted linearly-polarized orthogonal field vectors ($\vec{E}_v$, $\vec{E}_h$) undergoing Faraday rotation to produce received orthogonal vectors ($\vec{E}_{v'}$, $\vec{E}_{h'}$).

FIGURE 2
Faraday rotation in the plane normal to the propagation direction



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Cross- and co-polar attenuations, A_{xF} and A_{cF} , respectively, due to Faraday rotation are given by:

$$A_{xF} = -20 \log[\cos(\theta_F)] \quad (\text{dB}) \quad (3a)$$

$$A_{cF} = -20 \log[\sin(\theta_F)] \quad (\text{dB}) \quad (3b)$$

where the Faraday rotation angle θ_F is given by:

$$\theta_F = 2.36 \times 10^{-14} \frac{B_{av} N_T}{f^2} \quad (\text{rad}) \quad (4)$$

where:

f : frequency (GHz)

N_T : total electron density (electrons m^{-2})

B_{av} : Earth's magnetic field (Tesla)

noting that $A_{xF} \rightarrow \infty$ as $\theta_F \rightarrow (2n + 1)\pi/2$ for $n = 0, 1, 2, \dots$

and that $A_{cF} \rightarrow \infty$ as $\theta_F \rightarrow 2n\pi$ for $n = 0, 1, 2, \dots$

Typical values for θ_F are given in Fig. 1 of Recommendation ITU-R P.531-13.

The matrix equation (5) can be used to recover values of transmitted linearly polarized vectors (E_v, E_h) from the corresponding received values (E_v', E_h') after undergoing Faraday rotation.

$$\begin{bmatrix} E_v \\ E_h \end{bmatrix} = \begin{bmatrix} \cos \theta_F & \sin \theta_F \\ -\sin \theta_F & \cos \theta_F \end{bmatrix} \begin{bmatrix} E_v' \\ E_h' \end{bmatrix} \quad (5)$$

2.2.3 Hydrometeor depolarization

Hydrometeor depolarization is another way of changing the polarization of RF signals, and hence leading to depolarization loss. Hydrometeor depolarization is usually described by the cross polarization discrimination ratio XPD which is the ratio of the power with the expected polarization to the power with the orthogonal polarization in dB units as reported in Recommendation ITU-R P.310.

The polarization discrimination ratio is used as a measure of the degree of interference between orthogonally-polarized channels and it reaches ∞ dB when the power with orthogonal polarization reaches zero. On the other hand, XPD values reach $-\infty$ dB when power with expected polarization has null values.

By considering the expected polarization direction q as the direction of like polarization, the propagation loss factor A_{xq} due to hydrometeor depolarization can be written as:

$$A_{xq} = -20 \log \left\{ \cos \left(\tan^{-1} \left\{ 10^{\frac{-XPD_q}{20}} \right\} \right) \right\}, \quad q = v, h, c \quad (6)$$

In the above, v , h , and c stand for vertical polarization, horizontal polarization, and circular polarization respectively. Based on equation (6), when the polarization of propagating signal align along expected polarization direction, $XPD_q \rightarrow \infty$, and $A_{xq} \rightarrow 0$. On the other hand, when polarization of propagating signal is orthogonal to direction of expected polarization, $XPD_q \rightarrow -\infty$, and $A_{xq} \rightarrow \infty$.

XPD_q in equation (6) can be obtained from § 4.1 of Recommendation ITU-R P.618-12 by setting the proper value of the polarization angle τ in equation (70) of Recommendation ITU-R P.618-12. For instance, in case of vertical polarization, to $\tau = \pi/2$ and in case of horizontal polarization $\tau = 0$. The current ITU-R Depolarization Prediction Procedure in Recommendation ITU-R P.618 does include a term which accounts for additional XPD due to ice particle depolarization. The ITU procedure determines the XPD due to rain from the copolar attenuation (either measured or calculated

from the ITU-R Rain Attenuation Prediction Procedure in Recommendation ITU-R P.618). Then an additional *XPD* degradation due to ice particles in the path is determined by an empirical estimate based on the statistics of ice depolarization as related to coincident rain depolarization.

2.3 Attenuation due to atmospheric gasses A_g (dB)

The attenuation due to absorption by atmospheric gasses, A_g (dB), is a complicated function of frequency, according to the varying attenuation rates of oxygen and water vapour with frequency as described in Recommendation ITU-R P.676.

The attenuation increases as path elevation angle decreases, due to the longer path in the atmosphere, and decreases with the altitude of the Earth-based station, due to the shorter path in the atmosphere and its lower density.

At many frequencies water-vapour is the dominant cause of attenuation. At such frequencies, in addition to the foregoing geometrical factors, there is both spatial and temporal variability of the attenuation due to water-vapour density, which varies with location and weather.

Recommendation ITU-R P.836 provides digital global maps of surface water-vapour density exceeded for a range of percentage times of an average year or of a month at a given location.

Recommendation ITU-R P.453 gives expressions relating water-vapour density and relative humidity. The highest possible water-vapour density at any time and location is limited to the value corresponding to 100% relative humidity. Some of the higher values of water-vapour density in the Recommendation ITU-R P.836 data maps are only possible at temperatures well above local annual mean values.

Attachment C gives a method for calculating the attenuation due to atmospheric gasses. The calculation takes the altitude of the Earth-based station into account, and is extended for ray elevation angles down to -2 degrees. Although negative apparent ray elevation angles would not normally be considered for a wanted Earth-space link, such a path might be significant when evaluating interference.

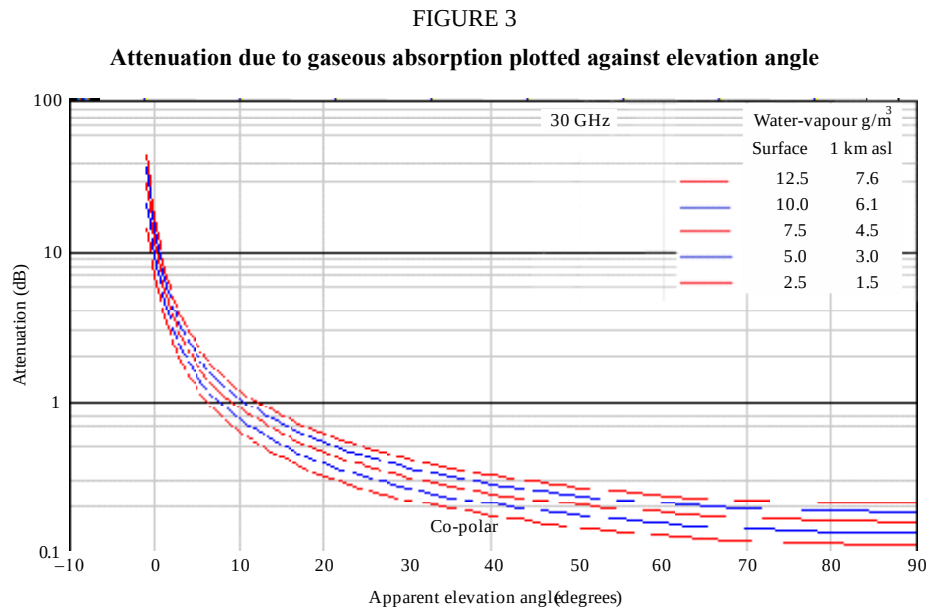
Attachment A gives a method for calculating the free-space elevation angle.

Attachment B gives a method for calculating the apparent elevation angle given the free-space elevation angle.

The method in Attachment C is valid over the frequency range 1 GHz to 1 000 GHz. Gaseous attenuation can be ignored below 1 GHz. For large values of elevation angle, in some situations, it might be valid to ignore gaseous attenuation at somewhat higher frequencies.

Figure 3 gives examples of results from the method in Attachment C for an Earth-based station at a ground and station altitude of 1 km above sea level. Total gaseous attenuation in dB is plotted against apparent elevation angle for a frequency of 30 GHz, for five values of sea-level water-vapour density, 7.5 g/m³ being the reference global mean. The corresponding surface water-vapour densities at the ground level of 1 km above sea level ρ for this calculation are obtained by the scaling according to $\rho = \rho_0 \exp\left(\frac{-h}{2}\right)$ g/m³ where ρ_0 g/m³ is the sea-level surface density. The Figure illustrates this effect of altitude on water-vapour density by listing their values at both sea level and 1 km above sea level.

Figure 3 demonstrates the rapid rise of gaseous attenuation as the elevation angle decreases towards zero. The attenuation on Earth-space paths is sometimes assumed to be negligible below about 10 GHz. This may not be true for paths with low elevation angles. For elevation angles below about 10 degrees it is recommended that the calculation is performed for any frequency above 1 GHz.



2.4 Loss due to beam spreading A_{bs} (dB)

Refractive effects in the atmosphere result in the apparent elevation angle at an Earth-based station being higher than the elevation angle of the straight line to the space station, especially at low elevation angles. The effect is small above about 5 degrees, but can be significant for lower elevation angles. Attachment B gives methods for converting between these two elevation angles.

Sub-section 2.4.1 described atmospheric effects which cause ray bending.

Sub-section 2.4.2 gives a method for calculation the attenuation or enhancement due to de-focussing or focusing caused by atmospheric refractivity.

2.4.1 Ray bending

The following sub-sections, 2.4.1.1 and 2.4.1.2, describe the two mechanisms causing atmospheric refraction, tropospheric and ionospheric.

2.4.1.1 Tropospheric refraction

The frequency independent variations are stemming from variations of the pressure, P , water vapour pressure e , and temperature T , and it is given by:

$$n = 1 + 10^{-6} \times N = 1 + 10^{-6} \times \left[\frac{77.6}{T} \left(p + e + 4810 \frac{e}{T} \right) \right] \quad (7)$$

In the above N is the refractivity, P and e are in hPa units, and T is in Kelvin. In addition, equation (7) can be applied at frequencies up to 100 GHz.

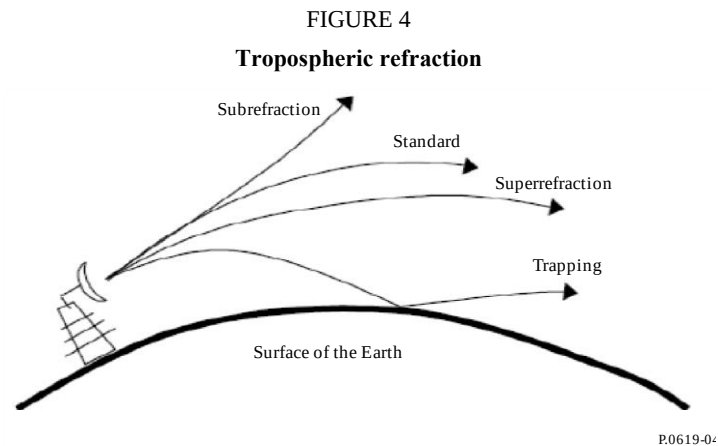
The frequency dependence variations are attributed to the absorption spectral lines of atmospheric gasses, especially oxygen and water vapour. Contributions of those spectral lines to the atmospheric refractive index can be obtained from Recommendation ITU-R P.676-11 and they can be ignored at frequencies below 10 GHz.

For ease of geometrical analysis, the tropospheric refracted rays can be represented as straight lines then compensation is done by assuming an imaginary earth radius, otherwise referred to as effective earth radius, R_e . The ratio between the effective R_e and true earth radius a is referred to as the effective earth radius factor (k -factor) and is given by:

$$k = \frac{R_e}{a} = 1 + a \frac{dn}{dh} = \frac{1}{1 + \frac{dN/dh}{157}} \quad (8)$$

with $\frac{dn}{dh}$ is the refractive index gradient with atmospheric height h .

Depending on k-factor value, the tropospheric refraction can be characterized as normal refraction, sub-refraction, super-refraction and ducting as shown in Fig. 4 and explained below.



When:

$$k = \frac{4}{3} \quad (9a)$$

Normal refraction occurs, and RF rays travel on a straight line path along the earth's surface and go out to space unobstructed.

If:

$$\frac{4}{3} > k > 0 \quad (9b)$$

sub-refraction occurs, meaning that radio waves propagate away from the earth's surface.

When:

$$\infty > k > \frac{4}{3} \quad (9c)$$

super-refraction occurs and RF rays propagate towards the earth's surface thus extending the radio horizon.

Finally, if:

$$-\infty < k < 0 \quad (9d)$$

ducting occurs and the RF rays bend downwards with a curvature greater than that of the earth. This is also called trapping.

2.4.1.2 Ionospheric refraction

Figure 5 provides examples of ray signals transmitted at different frequencies by a transmitter located on the ground surface. Rays propagating at vertical incidence into the ionosphere with frequencies above the maximum critical frequency (f_oF_2) of the F2 ionospheric layer, pass through the ionosphere. If the propagation direction of those rays deviates away from the vertical incidence direction, the rays undergo refraction before passing through the ionosphere as shown by ray 4 and ray 5 in Fig. 5. Some of those rays may be refracted enough to be reflected back to the ground as shown by ray 6 in Fig. 5.