

EFFECTS OF TROPOSPHERIC REFRACTION ON RADIOWAVE PROPAGATION

(Question ITU-R 201/3)

(1992-1994)

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of terrestrial and Earth-space links it is necessary to have appropriate calculation procedures for assessing the refractivity effects on radio signals;
- b) that procedures have been developed that allow the calculation of some refractive propagation effects on radio signals on terrestrial and Earth-space links,

recommends

- 1. that the information in Annex 1 be used for the calculation of large-scale refractive effects.

ANNEX 1

1. Ray bending

A radio ray passing through the lower (non-ionized) layer of the atmosphere undergoes bending caused by the gradient of the refractive index (see Recommendation ITU-R PN.369). Since the refractive index varies mainly with altitude, only the vertical gradient of the refractive index is generally considered. The curvature at a point is therefore contained in the vertical plane and is expressed by:

$$\frac{1}{\rho} = - \frac{\cos \varphi}{n} \frac{dn}{dh} \quad (1)$$

where:

- ρ : radius of curvature of the ray path
- n : refractive index of the atmosphere
- dn/dh : vertical gradient of refractive index
- h : height of the point above the Earth's surface
- φ : angle of the ray path with the horizontal at the point considered.

This ray curvature is defined as positive for ray bending towards the Earth's surface. This phenomenon is virtually independent of frequency, if the index gradient does not vary significantly over a distance equal to the wavelength.

2. Effective Earth radius on an approximately horizontal path

If the path is approximately horizontal, φ is close to zero. However, since n is very close to 1, equation (1) is simplified as follows:

$$\frac{1}{\rho} = - \frac{dn}{dh} \quad (2)$$

It is therefore clear that if the vertical gradient is constant, the trajectories are arcs of a circle.

A well-known transformation allows propagation to be considered as rectilinear above a hypothetical Earth of effective radius $R_e = k a$, where:

$$\frac{1}{k a} = \frac{1}{a} + \frac{dn}{dh} = \frac{1}{R_e} \quad (3)$$

where a is the actual Earth radius, and k is the effective earth radius factor. The exponential model of the refractive index (see Recommendation ITU-R PN.369), used in the first kilometre of the atmosphere, can be approximated by a linear one corresponding to an effective Earth radius with $k = 4/3$.

3. Modified refractive index

For some applications, for example for ray tracing, a modified refractive index or refractive modulus is used, defined in Recommendation ITU-R PN.310. The refractive modulus M is given by:

$$M = N + \frac{h}{a} \quad (4)$$

h being the height of the point considered expressed in metres and a the Earth's radius expressed in thousands of kilometres. This transformation makes it possible to refer to propagation over a flat Earth surmounted by an atmosphere whose refractivity would be equal to the refractive modulus M .

4. Apparent boresight angle on slant paths

The decrease in refractive index with height will produce an increase $\Delta\theta$ in the apparent elevation angle for an elevated source. There will be fluctuations about this apparent angle due to local variations in the refractive-index structure. Table 1 presents the average angular deviation values for propagation through the total atmosphere. It summarizes experimental data obtained by radar techniques, with a radiometer and a radiotelescope.

TABLE 1

Angular deviation values for propagation
through the total atmosphere

Elevation angle θ (degrees)	Average total angular deviation, $\Delta\theta$ (degrees)			
	Polar continental air	Temperate continental air	Temperate maritime air	Tropical maritime air
1	0.45	–	–	0.65
2	0.32	0.36	0.38	0.47
4	0.21	0.25	0.26	0.27
10	0.10	0.11	0.12	0.14
20		0.05	0.06	
30		0.03	0.04	
Day-to-day variation in $\Delta\theta$ (for columns 1 and 4 only)				
1	0.1 r.m.s.			
10	0.007 r.m.s.			

5. Beam spreading on slant paths

Signal loss may also result from additional spreading of the antenna beam caused by the variation of atmospheric refraction with the elevation angle. This effect should be negligible for all elevation angles above 3°. Figure 1 gives an estimate of the losses through the total atmosphere due to atmospheric refraction effects. Losses should be independent of frequency over the range 1-100 GHz where water vapour is contributing to the refractive profile.

FIGURE 1
An estimate of loss due to the additional spreading of a beam
and standard deviation about the average

