

Space Environment TOPICS



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SE-14

The Ionosphere

It is surprising to most people that the ionosphere makes up less than one percent of the mass of the atmosphere above 100 km (see figure 1). Even though the ionosphere only contains a small fraction of atmospheric material, it is very important because of its influence on the passage of radio waves. Most of the ionosphere is electrically neutral, but when solar radiation strikes the chemical constituents of the atmosphere electrons are dislodged from atoms and molecules to produce the ionospheric plasma. This occurs on the sunlit side of the Earth, and only the shorter wavelengths of solar radiation, (the extreme ultraviolet and X-ray part of the spectrum), are energetic enough to produce this ionization. The presence of these charged particles makes the upper atmosphere an electrical conductor, which supports electric currents and affects radio waves.

Ionospheric Characteristics

The ionosphere has historically been divided into regions (D, E, and F), with the term “layer” referring to the ionization within a region. The



Figure 1. The ionosphere lies well above where aircraft fly, but is located at altitudes where many satellites and the Space Shuttle orbit.

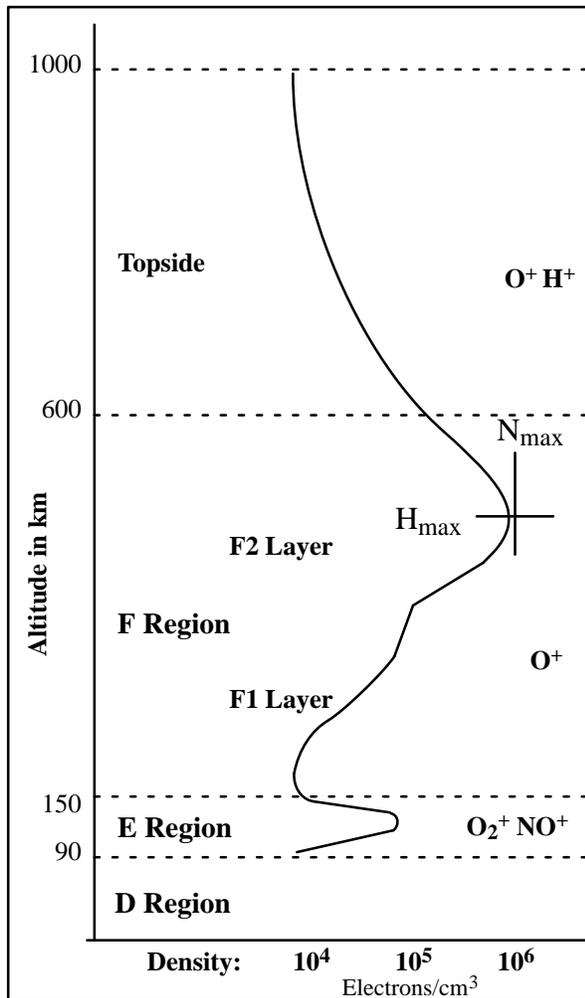


Figure 2. Various layers of the ionosphere and their predominant ion populations are listed at their respective heights above ground. The density in the ionosphere varies considerably, as shown.

lowest is the D-region, covering altitudes between about 50 and 90 km. The E-region lies between 90 and 150 km, and the F-region is the ionosphere above the E-region. Within the E-region is the normal E layer, produced by solar radiation, and sporadic layers, designated Es. Within the F-region are the F1 and F2 layers. The top of the ionosphere is at about 1000 km, but there is no real boundary between the plasma in the ionosphere and the outer reaches of the Earth's magnetic field, the plasmasphere and magnetosphere. Figure 2 shows the ionospheric layers and the principle ions that compose each region. One important layer from the standpoint of Navigation and Communication

customers is the F2 layer, where electron concentrations reach their highest values.

At high latitudes there is another source of ionization called the aurora. The aurora is a display of lights caused by electrons and protons striking the atmosphere at high speed. The particles come from the magnetosphere and spiral down the magnetic field lines of the Earth. These particles produce a spectacular array of light, and when they strike the atmosphere they also produce ionization. The auroral oval is named because of its shape, and exists in both the Northern and Southern hemispheres above about 60 degrees geomagnetic latitude (*see* "Aurora", Space Environment Topics SE-12).

At low latitudes the largest electron densities are found in peaks on either side of the magnetic equator; this is a feature known as the equatorial anomaly. The peak ionospheric concentrations do not occur on the equator, as might be expected from the maximum in solar ionizing radiation, but instead are displaced on either side. This peculiarity is due to the geometry of the magnetic field and the presence of electric fields. The electric fields that transport the plasma are caused by a polarizing effect of the thermospheric winds.

Ionospheric Variability

The ionosphere varies greatly because of changes in the two sources of ionization and because it responds to changes in the neutral part of the upper atmosphere in which it is embedded. This region of the atmosphere is known as the thermosphere. Since it responds to solar EUV radiation, the ionosphere varies over the 24-hour period between daytime and nighttime and over the 11-year cycle of solar activity. This variability is captured in Table 1, which illustrates changes in the F-region maximum electron density (N_{\max}) for the diurnal variation and over the solar cycle. On shorter time-scales, solar X-ray radiation can increase

dramatically when a solar flare occurs; this increases the D- and E-region ionization. During a geomagnetic storm the auroral source of ionization becomes much more intense and variable, and expands to lower latitudes. In extreme cases auroral displays can be seen as far south as Mexico.

The other main source of variability in the ionosphere comes from charged particles responding to the neutral atmosphere in the thermosphere. The ionosphere responds to the thermospheric winds; they can push the ionosphere along the inclined magnetic field lines to a different altitude. The ionosphere also responds to the composition of the thermosphere, which affects the rate that ions and electrons recombine. During a geomagnetic storm, the energy input at high latitudes produces waves and changes in thermospheric winds and composition. This produces both increases (“positive phases”) and decreases (“negative phases”) in the electron concentration.

Table 1 presents the diurnal and solar cycle variability of three important ionospheric parameters: N_{\max} , MUF and TEC. For HF communication the radio waves propagate from one location to another by bouncing off the ionosphere. The critical parameters are the maximum and lowest usable frequencies (MUF and LUF) that the ionosphere can “support.” The MUF depends on the peak electron density in the F-region and the angle of incidence of the radio wave. This changes through the day, over the solar cycle, and during geomagnetic distur-

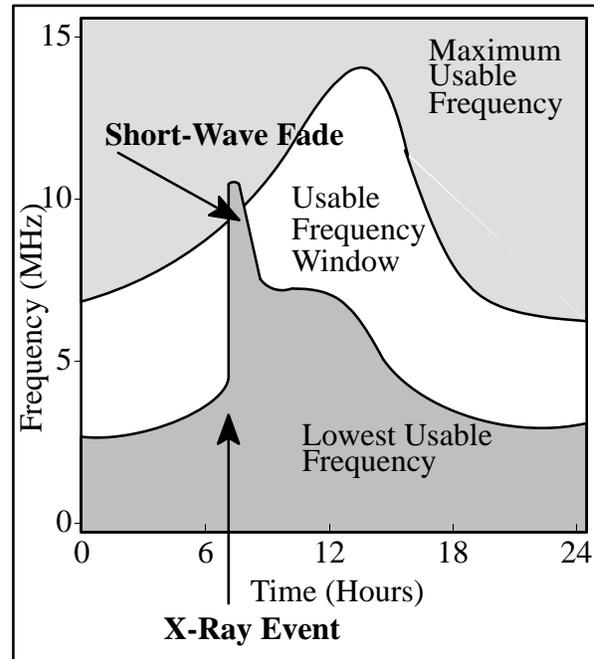


Figure 3. The usage frequency window for radio propagation lies between the lowest and maximum usable frequencies. When the window closes, as shown here, a shortwave fade occurs.

bances. The LUF is controlled by the amount of absorption of the radio wave in the D- and E-region, and is severely affected by solar flares (figure 3). Total Electron Content (TEC) is an important ionospheric parameter for navigation customers. All single-frequency GPS receivers (over a million users) must correct for the delay of the GPS signal as it propagates through the ionosphere from GPS satellites (22,000 km altitude). TEC is a measure of this delay, and it is required if an accurate position location is to be provided by the GPS receiver.

Table 1. Ionospheric Variability

| Ionospheric Parameter | Diurnal (Mid-Latitude) | Solar Cycle (Daytime) |
|--------------------------|--|---|
| N_{\max} | 1×10^5 to 1×10^6 electrons/cm ³ Factor of 10 | 4×10^5 to 2×10^6 electrons/cm ³ Factor of 5 |
| Maximum Usable Frequency | 12 to 36 MHz Factor of 3 | 21 to 42 MHz Factor of 2 |
| Total Electron Content | 5 to 50×10^{16} electrons/m ² Factor of 10 | 10 to 50×10^{16} electrons/m ² Factor of 5 |

The variability in TEC over the diurnal and solar cycle periods is also shown in Table 1.

Ionospheric Scintillation

There are certain regions of the ionosphere (mainly the high latitude and low latitude F-region,) and certain local times (principally after sunset) when the ionosphere may become highly turbulent. “Turbulence” is defined here as the presence of small-scale (from centimeters to meters) structures or irregularities imbedded in the large-scale (tens of kilometers) ambient ionosphere. Under favorable conditions, plasma density irregularities are generated just after sunset in the equatorial region and may last for several hours. At high latitudes, these irregularities may be generated during either the daytime or at night. For both low and high latitude regions these small-scale irregularities occur most frequently during the solar cycle maximum period (see figure 4).

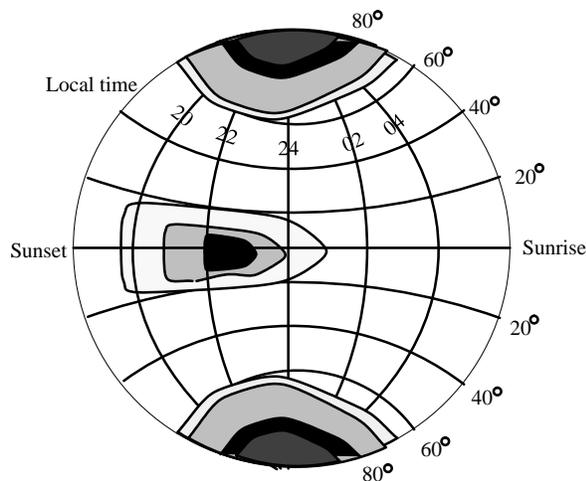


Figure 4. Global depth of scintillation fading during low and moderate solar activity.

The existence of these small-scale structures can seriously affect the nature of radio waves as they propagate through the ionosphere where they are imbedded. Figure 5 shows the effect on the amplitude of a UHF (~250 Mhz frequen-

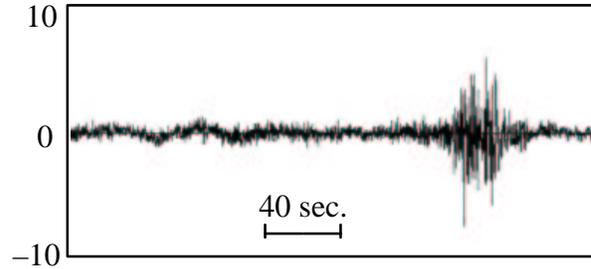


Figure 5. A signal is disrupted by the onset of scintillation in the ionosphere.

cy) radio wave propagating through a “clear” environment that abruptly becomes filled with small-scale irregularities. The term “ionospheric scintillation” has been used to describe this effect on the radio signals. The bigger the amplitude fluctuations of the scintillated signal the greater the impact on Communication and Navigation systems.



References

The references listed below provide much more information on ionospheric phenomena for the interested reader.

- Davies, K., “Ionospheric Radio,” IEE Electromagnetic Waves series 31, Peter Peregrinus Ltd., London, UK, 1989.
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