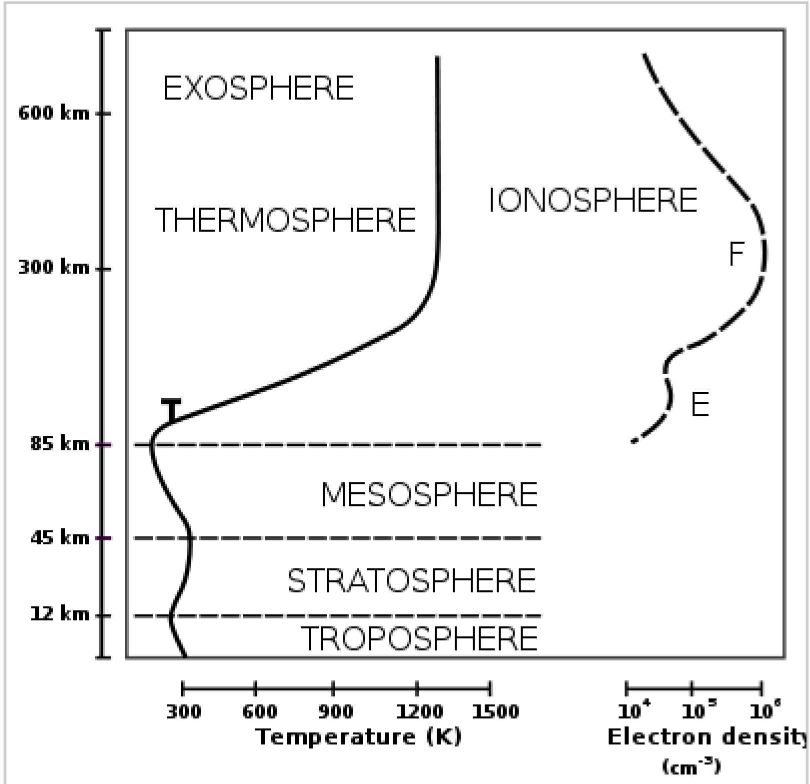
Ionosphere

From Wikipedia, the free encyclopedia

The **ionosphere** is the uppermost part of the atmosphere, distinguished because it is ionized by solar radiation. It plays an important part in atmospheric electricity and forms the inner edge of the magnetosphere. It has practical importance because, among other functions, it influences radio propagation to distant places on the Earth.[1]



Relationship of the atmosphere and ionosphere

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The ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth, stretching from a height of about 50 km to more than 1000 km. It owes its existence primarily to ultraviolet radiation from the sun.

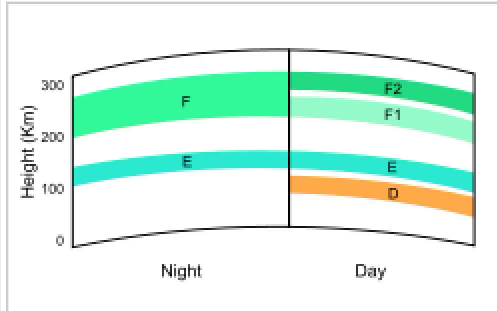
The lowest part of the Earth's atmosphere, the troposphere extends from the surface to about 10 km (6 miles). Above 10 km is the stratosphere, followed by the mesosphere. In the stratosphere incoming solar radiation creates the ozone layer. At heights of above 80 km (50 miles), in the thermosphere, the atmosphere is so thin that free electrons can exist for short periods of time before they are captured by a nearby positive ion. The number of these free electrons is sufficient to affect radio propagation. This portion of the atmosphere is *ionized* and contains a plasma which is referred to as the ionosphere. In a plasma, the negative free electrons and the positive ions are attracted to each other by the electromagnetic force, but they are too energetic to stay fixed together in an electrically neutral molecule.

Ultraviolet (UV), X-Ray and shorter wavelengths of solar radiation are *ionizing,* since photons at these frequencies contain sufficient energy to dislodge an electron from a neutral gas atom or molecule upon absorption. In this process the light electron obtains a high velocity so that the temperature of the created electronic gas is much higher (of the order of thousand K) than the one of ions and neutrals. The reverse process to Ionization is recombination, in which a free electron is "captured" by a positive ion, occurs spontaneously. This causes the emission of a photon carrying away the energy produced upon recombination. As gas density increases at lower altitudes, the recombination process prevails, since the gas molecules and ions are closer together. The balance between these two processes determines the quantity of ionization present.

Ionization depends primarily on the Sun and its activity. The amount of ionization in the ionosphere varies greatly with the amount of radiation received from the sun. Thus there is a diurnal (time of day) effect and a seasonal effect. The local winter hemisphere is tipped away from the Sun, thus there is less received solar radiation. The activity of the sun is associated with the sunspot cycle, with more radiation occurring with more sunspots. Radiation received also varies with geographical location (polar, auroral zones, mid-latitudes, and equatorial regions). There are also mechanisms that disturb the ionosphere and decrease the ionization. There are disturbances such as solar flares and the associated release of charged particles into the solar wind which reaches the Earth and interacts with its geomagnetic field.

The ionospheric Layers

At night the F layer is present while the ionization in the E- and D-layers is extremely small. During the day, a D and an E.layer form and the F layer becomes much stronger and often appears a deformation in its profile that is called F1. F2, however, is by day and night the main Maximum in the F-region and is crucial for the transmission of radio waves.



Ionospheric layers.

Solar radiation, acting on the height-dependent composition of the atmosphere, generates different ionized layers so that wave propagation may occur on different ways.

D layer

The D layer is the innermost layer, 60 km to 90 km above the surface of the Earth. Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometre (nm) ionizing nitric oxide (NO). In addition, with high Solar activity hard X-rays (wavelength < 1 nm) may ionize (N_2, O_2). During the night cosmic rays produce a residual amount of ionization. Recombination is high in the D layer, the net ionization effect is low, but loss of wave energy is great due to frequent collisions of the electrons (about ten collisions every msec). As a result high-frequency (HF) radio waves are not reflected by the D layer but suffer loss of energy therein. This is the main reason for absorption of HF radio waves, particularly at 10 MHz and below, with progressively smaller absorption as the frequency gets higher. The absorption is small at night and greatest about midday. The layer reduces greatly after sunset, a small rest remains due to galactic cosmic rays. A common example of the D layer in action is the disappearance of distant AM broadcast band stations in the daytime.

During solar proton events, ionization can reach unusually high levels in the D-region over high and polar latitudes. Such very rare events are known as Polar Cap Absorption (or PCA) events, because the increased ionization significantly enhances the absorption of radio signals passing through the region. In fact, absorption levels can increase by many tens of dB during intense events, which is enough to absorb most (if not all) transpolar HF radio signal transmissions. Such events typically last less than 24 to 48 hours.

E layer

The E layer is the middle layer, 90 km to 120 km above the surface of the Earth. Ionization is due to soft X-ray (1-10 nm) and far ultraviolet (UV) solar radiation ionization of molecular oxygen (O_2). Normally, at oblique incidence, this layer can only reflect radio waves having frequencies lower than about 10 MHz and may contribute a bit to absorption on frequencies above. However during intense Sporadic E events the E_s layer can reflect frequencies up to 50 MHz and higher.The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer rapidly disappears because the primary source of ionization is no longer present. After sunset an increase in the height of the E layer maximum increases the range to which radio waves can travel by reflection from the layer.

This region is also known as the Kennelly-Heaviside Layer or simply the Heaviside layer. Its existence was predicted in 1902 independently and almost simultaneously by the American electrical engineer Arthur Edwin Kennelly (1861-1939) and the British physicist Oliver Heaviside (1850-1925). However, it was not until 1924 that its existence was detected by Edward V. Appleton.

E_s

The E_s layer (sporadic E-layer) is characterized by small, thin clouds of intense ionization, which can support reflection of radio waves, rarely up to 225 MHz. Sporadic-E events may last for just a few minutes to several hours. Sporadic E propagation makes radio amateurs very excited, as propagation paths that are generally unreachable can open up. There are multiple causes of sporadic-E that are still being pursued by researchers. This propagation occurs most frequently during the summer months when high signal levels may be reached. The skip distances are generally around 1000 km (620 miles). VHF TV and FM broadcast DX'ers also get excited as their signals can be bounced back to Earth by Es. Distances for one hop propagation can be as close as 900 km [500 miles] or up to 2500 km (1,400 miles). Douple-hop reception over 3500 km (2,000 miles) is possible, too.

F layer

The F layer or region, also known as the Appleton layer extends from about 200 km to more than 500 km above the surface of Earth. It is the top most layer of the ionosphere. Here extreme ultraviolet (UV, 10–100 nm) solar radiation ionizes atomic oxygen. The F layer consists of one layer at night, but during the day, a deformation often forms in the profile that is labeled F_1. The F_2 layer remains by day and night responsible for most skywave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances.

From 1972 to 1975 NASA launched the AEROS and AEROS B satellites to study the F region.[2]

Ionospheric model

An ionospheric model is a mathematical description of the ionosphere as a function of location, altitude, day of year, phase of the sun spot cycle and geomagnetic activity. Geophysically, the state of the ionospheric plasma may be described by four parameters: *electron density, electron and ion temperature* and, since several species of ions are present, *ionic composition*. Radio propagation depends uniquely on electron density.

Models are usually expressed as computer programs. The model may be based on basic physics of the interactions of the ions and electrons with the neutral atmosphere and sun light, or it may be a statistical description based on a large number of observations or a combination of physics and observations. One of the most widely used models is the International Reference Ionosphere (IRI)[3](IRI 2007), which is based on data and specifies the four parameters just mentionned. The IRI is an international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI).[4] The major data sources are the worldwide network of ionosondes, the powerful incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin), the ISIS and Alouette topside sounders, and in situ instruments on several satellites and rockets. IRI is updated yearly. IRI will be established in 2009 by the International Organization for Standardization (ISO) as standard TS16457. IRI is accurate in describing the variation of the electron density from bottom of the ionosphere to the altitude of maximum density than in describing the total electron content (TEC).

Anomalies to the ideal model

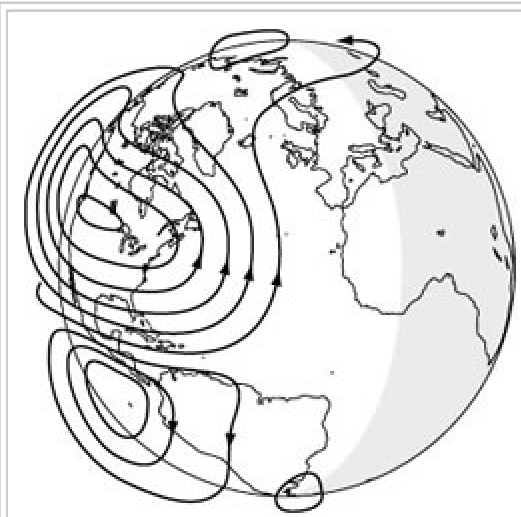
Ionograms allow deducing not only the shape of the different layers but also the structure of the electron/ion-plasma. Rough traces, indicating nonhomogeneity, are seen predominantly at night and at higher latitudes, and during disturbed conditions.

Winter anomaly

At mid-latitudes, the F_2 layer daytime ion production is higher in the summer, as expected, since the sun shines more directly on the earth. However, there are seasonal changes in the molecular-to-atomic ratio of the neutral atmosphere that cause the summer ion loss rate to be even higher. The result is that the increase in the summertime loss overwhelms the increase in summertime production, and total F_2 ionization is actually lower in the local summer months. This effect is known as the winter anomaly. The anomaly is always present in the northern hemisphere, but is usually absent in the southern hemisphere during periods of low solar activity.

Equatorial anomaly

Within approximately ± 20 degrees of the *magnetic equator*, is the *equatorial anomaly*. It is the occurrence of a trough of concentrated ionization in the F_2 layer. The Earth's magnetic field lines are horizontal at the magnetic equator. Solar heating and tidal oscillations in the lower ionosphere move plasma up and across the magnetic field lines. This sets up a sheet of electric current in the E region which, with the horizontal magnetic field, forces ionization up into the F layer, concentrating at ± 20 degrees from the magnetic equator. This phenomenon is known as the *equatorial fountain*.


Electric currents created in sunward ionosphere.

Equatorial electrojet

The worldwide solar-driven wind results in the so-called Sq (solar quiet) current system in the E region of the Earth's ionosphere (100–130 km altitude). Resulting from this current is an electrostatic field directed E-W (dawn-dusk) in the equatorial day side of the ionosphere. At the magnetic dip equator, where the geomagnetic field is horizontal, this electric field results in an enhanced eastward current flow within ± 3 degrees of the magnetic equator, known as the equatorial electrojet.

Ionospheric perturbations

X-rays: sudden ionospheric disturbances (SID)

When the sun is active, strong solar flares can occur that will hit the Earth with hard X-rays on the sunlit side of the Earth. They will penetrate to the D-region, release electrons which will rapidly increase absorption causing a High Frequency (3-30 MHz) radio blackout. During this time Very Low Frequency (3 – 30 kHz) signals will become reflected by the D layer instead of the E layer, where the increased atmospheric density will usually increase the absorption of the wave, and thus dampen it. As soon as the X-rays end, the sudden ionospheric disturbance (SID) or radio black-out ends as the electrons in the D-region recombine rapidly and signal strengths return to normal.

Protons: polar cap absorption (PCA)

Associated with solar flares is a release of high-energy protons. These particles can hit the Earth within 15 minutes to 2 hours of the solar flare. The protons spiral around and down the magnetic field lines of the Earth and penetrate into the atmosphere near the magnetic poles increasing the ionization of the D and E layers. PCA's typically last anywhere from about an hour to several days, with an average of around 24 to 36 hours.

Geomagnetic storms

A geomagnetic storm is a temporary intense disturbance of the Earth's magnetosphere.

- During a geomagnetic storm the F_2 layer will become unstable, fragment, and may even disappear completely.
- In the Northern and Southern pole regions of the Earth aurora will be observable in the sky.

Lightning

Lightning can cause ionospheric perturbations in the D-region in one of two ways. The first is through VLF frequency radio waves launched into the magnetosphere. These so-called "whistler" mode waves can interact with radiation belt particles and cause them to precipitate onto the ionosphere, adding ionization to the D-region. These disturbances are called Lightning-induced Electron Precipitation (LEP) events.

Additional ionization can also occur from direct heating/ionization as a result of huge motions of charge in lightning strikes. These events are called Early/Fast.

In 1925, C. F. Wilson proposed a mechanism by which electrical discharge from lightning storms could propagate upwards from clouds to the ionosphere. Around the same time, Robert Watson-Watt, working at the Radio Research Station in Slough, UK, suggested that the ionospheric sporadic E layer (Es) appeared to be enhanced as a result of lightning but that more work was needed. In 2005, C. Davis and C. Johnson, working at the Rutherford Appleton Laboratory in Oxfordshire, UK, demonstrated that the Es layer was indeed enhanced as a result of lightning activity. Their subsequent research has focussed on the mechanism by which this process can occur.

Radio application

DX communication, popular among amateur radio enthusiasts, is a term given to communication over great distances. Thanks to the property of ionized atmospheric gases to refract high frequency (HF, or shortwave) radio waves, the ionosphere can be utilized to "bounce" a transmitted signal down to ground. Transcontinental HF-connections rely on up to 5 bounces, or hops. Such communications played an important role during World War II. Karl Rawers most sophisticated prediction method [5] took account of several (zig-zag]paths, attenuation in the D-region and predicted the 11-years solar cycle by a method due to Wolfgang Gleißberg.

Mechanism of refraction

When a radio wave reaches the ionosphere, the electric field in the wave forces the electrons in the ionosphere into oscillation at the same frequency as the radio wave. Some of the radio-frequency energy is given up to this resonant oscillation. The oscillating electrons will then either be lost to recombination or will re-radiate the original wave energy. Total refraction can occur when the collision frequency of the ionosphere is less than the radio frequency, and if the electron density in the ionosphere is great enough.

The critical frequency is the limiting frequency at or below which a radio wave is reflected by an ionospheric layer at vertical incidence. If the transmitted frequency is higher than the plasma frequency of the ionosphere, then the electrons cannot respond fast enough, and they are not able to re-radiate the signal. It is calculated as shown below:

$$f_{critical} = 9 \times 10^{-3}\sqrt{N}$$

where N = electron density per cm^3 and $f_{critical}$ is in MHz.

The Maximum Usable Frequency (MUF) is defined as the upper frequency limit that can be used for transmission between two points at a specified time.

$$f_{muf} = \frac{f_{critical}}{\sin \alpha}$$

where α = angle of attack, the angle of the wave relative to the horizon, and sin is the sine function.

The cutoff frequency is the frequency below which a radio wave fails to penetrate a layer of the ionosphere at the incidence angle required for transmission between two specified points by refraction from the layer.

Other applications

The open system electrodynamic tether, which uses the ionosphere, is being researched. The space tether uses plasma contactors and the ionosphere as parts of a circuit to extract energy from the Earth's magnetic field by electromagnetic induction.

Measurements

Ionograms

Ionograms show the virtual heights and **critical frequencies** of the ionospheric layers and which are measured by an ionosonde. An ionosonde sweeps a range of frequencies, usually from 0.1 to 30 MHz, transmitting at vertical incidence to the ionosphere. As the frequency increases, each wave is refracted less by the ionization in the layer, and so each penetrates further before it is reflected. Eventually, a frequency is reached that enables the wave to penetrate the layer without being reflected. For ordinary mode waves, this occurs when the transmitted frequency just exceeds the peak plasma, or critical, frequency of the layer. Tracings of the reflected high frequency radio pulses are known as ionograms. Reduction rules are given in:"URSI Handbook of Ionogram Interpretation and Reduction", edited by *W.R.Piggott* and *Karl Rawer*, Elsevier Amsterdam 1961. Translations in Chinese, French, Japanese, Russian were edited by national organisations.

Incoherent scatter radars

Incoherent scatter radars operate above the critical frequencies. Therefore the technique allows to probe the ionosphere, unlike ionosondes, also above the electron density peaks. The thermal fluctuations of the electron density scattering the transmitted signals lack coherence, which gave the technique its name. Their power spectrum contains information not only on the density, but also on the ion and electron temperatures, ion masses and drift velocities.

Solar flux

Solar flux is a measurement of the intensity of solar radio emissions at a frequency of 2800 MHz made using a radio telescope located in Ottawa, Canada. Known also as the 10.7 cm flux (the wavelength of the radio signals at 2800 MHz), this solar radio emission has been shown to be proportional to sunspot activity. However, the level of the sun's ultraviolet and X-ray emissions is primarily responsible for causing ionization in the Earth's upper atmosphere. We now have data from the GOES spacecraft that measures the background **X-ray flux** from the sun, a parameter more closely related to the ionization levels in the ionosphere.

- The *A* and *K* indices are a measurement of the behavior of the horizontal component of the **geomagnetic field**. The *K* index uses a scale from 0 to 9 to measure the change in the horizontal component of the geomagnetic field. A new *K* index is determined at the Table Mountain Observatory, north of Boulder, Colorado.
- The geomagnetic activity levels of the earth are measured by the fluctuation of the Earth's magnetic field in SI units called teslas (or in non-SI gauss, especially in

older literature). The Earth's magnetic field is measured around the planet by many observatories. The data retrieved is processed and turned into measurement indices. Daily measurements for the entire planet are made available through an estimate of the *ap* index, called the *planetary A-index* (PAI).

Scientific research on ionospheric propagation

Scientists also are exploring the structure of the ionosphere by a wide variety of methods, including passive observations of optical and radio emissions generated in the ionosphere, bouncing radio waves of different frequencies from it, incoherent scatter radars such as the EISCAT, Sondre Stromfjord, Millstone Hill, Arecibo, and Jicamarca radars, coherent scatter radars such as the Super Dual Auroral Radar Network (SuperDARN) radars, and using special receivers to detect how the reflected waves have changed from the transmitted waves.

A variety of experiments, such as HAARP (High Frequency Active Auroral Research Program), involve high power radio transmitters to modify the properties of the ionosphere. These investigations focus on studying the properties and behavior of ionospheric plasma, with particular emphasis on being able to understand and use it to enhance communications and surveillance systems for both civilian and military purposes. HAARP was started in 1993 as a proposed twenty year experiment, and is currently active near Gakona, Alaska.

The SuperDARN radar project researches the high- and mid-latitudes using coherent backscatter of radio waves in the 8 to 20 MHz range. Coherent backscatter is similar to Bragg scattering in crystals and involves the constructive interference of scattering from ionospheric density irregularities. The project involves more than 11 different countries and multiple radars in both hemispheres.

Scientists are also examining the ionosphere by the changes to radio waves from satellites and stars passing through it. The Arecibo radio telescope located in Puerto Rico, was originally intended to study Earth's ionosphere.

History

In 1899, Nikola Tesla moved from New York to Colorado Springs, Colorado, where he would have room for his high-voltage, high-frequency experiments. Upon his arrival he told reporters that he was conducting wireless telegraphy experiments transmitting signals from Pikes Peak to Paris.[6] Tesla's diary contains explanations of his experiments concerning the ionosphere.[7]

Guglielmo Marconi received the first trans-Atlantic radio signal on December 12, 1901, in St. John's, Newfoundland (now in Canada) using a 152.4 m (500 ft) kite-supported antenna for reception. The transmitting station in Poldhu, Cornwall used a spark-gap transmitter to produce a signal with a frequency of approximately 500 kHz and a power of 100 times more than any radio signal previously produced. The message received was three dits, the Morse code for the letter **S**. To reach Newfoundland the signal would have to bounce off the ionosphere twice. Dr. Jack Belrose has recently contested this, however, based on theoretical and experimental work.[8] However, Marconi did achieve transatlantic wireless communications beyond a shadow of doubt in Glace Bay one year later.

In 1902, Oliver Heaviside proposed the existence of the *Kennelly-Heaviside Layer* of the ionosphere which bears his name. Heaviside's proposal included means by which radio signals are transmitted around the Earth's curvature. Heaviside's proposal, coupled with Planck's law of black body radiation, may have hampered the growth of radio astronomy for the detection of electromagnetic waves from celestial bodies until 1932 (and the development of high frequency radio transceivers). Also in 1902, Arthur Edwin Kennelly discovered some of the ionosphere's radio-electrical properties.

In 1912, the U.S. Congress imposed the Radio Act of 1912 on amateur radio operators, limiting their operations to frequencies above 1.5 MHz (wavelength 200 meters or smaller). The government thought those frequencies were useless. This led to the discovery of HF radio propagation via the ionosphere in 1923.

In 1926, Scottish physicist Robert Watson-Watt introduced the term *ionosphere* in a letter published only in 1969 in *Nature*:

> We have in quite recent years seen the universal adoption of the term ‘stratosphere’..and..the companion term ‘troposphere’... The term ‘ionosphere’, for the region in which the main characteristic is large scale ionisation with considerable mean free paths, appears appropriate as an addition to this series.

Edward V. Appleton was awarded a Nobel Prize in 1947 for his confirmation in 1927 of the existence of the ionosphere. Lloyd Berkner first measured the height and density of the ionosphere. This permitted the first complete theory of short wave radio propagation. Maurice V. Wilkes and J. A. Ratcliffe researched the topic of radio propagation of very long radio waves in the ionosphere. Vitaly Ginzburg has developed a theory of electromagnetic wave propagation in plasmas such as the ionosphere.

In 1962 the Canadian satellite Alouette 1 was launched to study the ionosphere. Following its success were Alouette 2 in 1965 and the two ISIS satellites in 1969 and 1971, all for measuring the ionosphere.

See also

- **Geophysics**
  - Van Allen radiation belt
  - Schumann resonances
  - International Reference Ionosphere
- **Radio**
  - Fading
  - Line-of-sight propagation
  - Ionospheric absorption
- **Related**
  - Tether propulsion
  - Canadian Geospace Monitoring
  - Pioneer Venus project

  - Nozomi
  - *New Horizons*
  - Soft gamma repeater
  - TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics)
  - International Geophysical Year
  - Upper Atmospheric Lightning
- **Lists**
  - List of astronomical topics
  - List of electronics topics

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3. ^ D.Bilitza:*International Reference Ionosphere 2000*.Radio Sci.36,#2,261-275 2001
4. ^ http://ccmc.gsfc.nasa.gov/modelweb/ionos/iri.html
5. ^ K. Rawer:*Wave Propagation in the Ionosphere*.Kluwer Acad.Publ., Dordrecht 1993
6. ^ Tesla biography at magnetricity.com (http://www.magnetricity.com/Tesla/Tesla_Biography.php)
7. ^ Tesla, Nikola, "The True Wireless". *Electrical Experimenter*, May 1919. (also at pbs.org (http://www.pbs.org/tesla/res/res_art06.html))
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External links

- Gehred, Paul, and Norm Cohen, *SWPC's Radio User's Page (http://www.sec.noaa.gov/radio)* .
- Amsat-Italia project on Ionospheric propagation (ESA SWENET website) (http://www.esa-spaceweather.net/sda/ionosfera/)
- was KN4LF NZ4O Solar Space Weather & Geomagnetic Data Archive (http://www.wcflunatall.com/nz4o1.htm)
- was KN4LF now NZ4O 160 Meter Radio Propagation Theory Notes (http://www.wcflunatall.com/nz4o5.htm) Layman Level Explanations Of "Seemingly" Mysterious 160 Meter (MF/HF) Propagation Occurrences
- USGS Geomagnetism Program (http://geomag.usgs.gov)
- Encyclopaedia Britannica, Ionosphere and magnetosphere (http://www.britannica.com/eb/article-9042708/ionosphere-and-magnetosphere)
- Current Space Weather Conditions (http://www.sec.noaa.gov/SWN/)
- Current Solar X-Ray Flux (http://www.sec.noaa.gov/rt_plots/xray_1m.html)
- Super Dual Auroral Radar Network (http://superdarn.jhuapl.edu/)
- European Inchorent Scatter radar system (http://www.eiscat.se/)
- Millstone Hill incoherent scatter radar (http://haystack.mit.edu/atm/mho/index.html)

Categories: Radio frequency propagation | Nikola Tesla | Atmosphere | Space plasmas | Plasma physics | Radio terminology