E-Layer auroral observations: Effect on modern communications

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Radiocommunication (AM, FM, military) and satellite-based navigation with global positioning systems (GPS) which have created a revolution in information transfer, now need weather forecasting of a different kind for their continued operation. They require an understanding of 'Aurora Borealis' (Figure 1), the amazing northern lights[1], because sources which create the aurora can be enough cause for concern to information technology in this global village.

The ionosphere is an upper region of the earth's atmosphere which contains ionized particles having a layered structure as revealed by radar studies. The lower E-layer of molecular ionization is at an altitude of 90–140 km from the earth, having an electron concentration sufficient to affect radio propagation. The F-layer of ionization is at a height upwards of 140 km. Both layers are of immense commercial significance as they guide radiowaves around the curvature of the earth, thereby influencing much of man's communication across distant points of the earth. An extreme form of an ionosphere disturbance is manifested in a brilliant display of aurora. Visualization of the lower ionosphere and prediction of auroral intensity gain importance in modern-day radio and satellite communications.

The space between the sun and the earth is filled with plasma gas (i.e. nuclei of atoms, mostly hydrogen and electrons, electrically neutral) called solar wind. In times of low solar activity, the solar wind flows radially outward from the sun at speeds varying between 300 and 500 km/s. The electrons and positive ions constituting the solar wind are repelled by the magnetic field of the earth. Near the earth, the magnetic field is compressed and neutralized in an outward direction into a limited space surrounding the earth called the magnetosphere. The charged particles from the solar wind are prevented from entering into the magnetosphere by the earth's magnetic field. Sometimes, electrically neutral particles do enter the magnetosphere, later decaying into electrons and positive ions. They form a circular belt of trapped charged particles surrounding the earth called the radiation belt or the Van Allen belt. One of the goals of solar research is the prediction of the effects on the magnetosphere of the earth created by the energy and charged particles released by the sun[2]. These solar effects include the aurora.

Figure 1. Natural aurora. Photo credit: Michael T. Dolan/Michigan Technological University.

The coupling between the ionosphere and the magnetosphere provides an insight into the electrodynamic health of the earth's environment. Monitoring of the geomagnetic field vectors (Figure 2) from observatories spread across the world provides ground-based magnetic records. The estimation of electromagnetic quantities in space point to the observation that a large amount of ionosphere currents can flow in regions where auroral activity is low[3].

Magnetospheric physicists have determined that auroras are powered by the solar wind; by quantities that determine the efficiency of the solar wind–magnetosphere generator and thus the auroral activity. They are solar wind speed, solar wind intensity and orientation of the solar wind magnetic field with respect to the earth's magnetic field. The luminous feature of the aurora occurs when different types of atoms and molecules in the earth's upper atmosphere collide with energized electrons. Red and green line emissions occur when excited atoms of atomic oxygen in the $O(^1D)$ and $O(^1S)$ states quench emitting photons with the wavelength $\lambda = 630.0$ nm (red emission) and $\lambda = 557.7$ nm (green emission), respectively. Nitrogen molecules present in the upper atmosphere, whether ionized or neutral, also produce several band emissions.

When the sun is active with intense solar flares, geomagnetic disturbances of large amplitude called a magnetic storm take place. These geomagnetic storms can in some cases induce electric currents in the earth that are known to interfere with electric power transmission equipment. They can cause failure of satellite systems. In the present context, the solar wind reaches supersonic speed (about

700 km/s) that creates imbalances in the magnetosphere.

Since auroral events occur in the upper region of the ionosphere powered by solar wind, could the lower E-region which is of such relevance to human communication be powered and an artificial aurora produced? This artificially created aurora would aid in understanding the E-region which previously could not be visualized. Such an experiment has been reported recently by Kagan *et al.*[4], who have found a new method of mapping ion clouds in the E-layer and photographing the green artificial airglow using charge-coupled-device (CCD) cameras.

About a decade ago, Bernhardt *et al.*[5] created an artificial airglow using high power radio waves radiated into the upper F-region of the atmosphere. This artificial airglow could be monitored by measuring airglow intensities, using photometers which consist of narrow-band interference filters, lenses and photomultiplier detectors. Using an intensified CCD camera, optical emission data were acquired. Powerful ground-based transmitters operating at 3.175 MHz up to a power of 400 kW produced ionosphere heating where the typical effective radiated power (ERP) employed was 200 MW. Light is emitted at visible wavelengths as the electrons excite neutral atoms in the F-layer of the atmosphere. The ionosphere heating produced by the radiowaves increases the electron temperature of the F-layer. This heating exerts a pressure inside this layer and a cavity is formed. The ionosphere is layered horizontally and is drifting. After the initial heating, the density cavity that is thermally formed and the heater beam from the transmitter are displaced in the direction of the plasma. The plasma drift direction and velocity are dependent on wind velocity. The airglow follows the direction of the drift. The ray paths of the electromagnetic wave are refracted by the plasma density gradients in the cavity. However, when further deflection by the cavity is not possible, the ray path changes and a new cavity is formed. The drifting cavities introduce moving ionosphere disturbances and bring about motion of the airglow clouds.

The pioneering experiment by Bernhardt *et al.*[5] showed how a 'searchlight' could be beamed from the earth to see the structure of the ionized F-layer. In the F-layer, ions are plentiful which allows high visibility when an electromagnetic wave is beamed at them, according to the description given earlier. But it is not so for the E-layer, where ions are scarce. In a recent experiment, while looking for the F-structure, Kagan *et al.*[4] observed emission from a layer 85–90 km above ground level. This emission came from the E-layer, previously undetected. These sporadic ion sources come from metal atoms ionized after a meteor burnout.

This has allowed the authors to demonstrate at Arecibo, Puerto Rico for the first time, the conversion of high power density electromagnetic waves into green line emission in the E-region. This region is away from the auroral zone of the F-layer. This experiment provides an important tool to observe the ion clouds in a region significant to modern communication. For high power radio wave source at a frequency of 3.175 MHz, with the highest HF level, an effective radiated power of about 80 MW was used. The obtained emission of 557.7 nm powered by the radio waves was very strong, up to 55 Rayleighs. The emission is seen in the thin plasma layers called sporadic-E layers (Es). The transmitted electromagnetic waves convert into Langmuir waves. These waves[6] are longitudinal electron plasma oscillations just above the plasma frequency, ω_p. The generation of these waves is due to a stream of available electrons. Wave–particle interactions cause the Langmuir waves to collapse and the thermally heated electrons excite atomic oxygen resulting in visible emissions. The radio waves are reflected by the E-layer plasma clouds and some pass through the 'holes' in the E-layer up to the F-layer where they are reflected back.

The sporadic-E structure visualized by the creation of an artificial aurora in the low altitude plasma layers is important in understanding the disruption in communication systems due to ionosphere disturbances. The Space Weather Programme addresses this and its effect on radiocommunications and satellite systems.

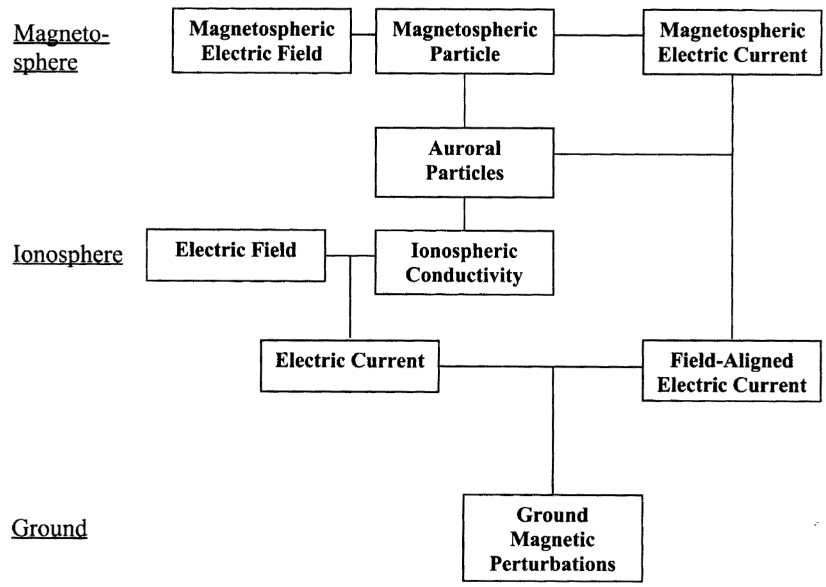

Figure 2. Coupling between the earth's magnetosphere and the ionosphere shown schematically [from ref. 3].

1. More pictures and references can be seen at the website: http://www.geo.mtu.edu/weather/aurora images.
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3. Kamide, Y., *Science*, 1988, **241**, 328–330.
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5. Bernhardt, P. A., Duncan, L. M. and Tepley, C. A., *Science*, 1988, **242**, 1022–1027.
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