GEOMAGNETISM AND ATMOSPHERIC LAYERS

Praveen B. Gawali

Earth is divided into different layers. Likewise, atmosphere too has many layers. The invention of mercury barometer led to the discovery of finite weight of air, and initially limited its extent to just 8 km. Later, it became clear atmosphere grew dense with increasing pressure, and temperature changed with height. Because of this, one cannot find a definite boundary to the atmosphere. It is transient and fleeting, which gradually and imperceptibly fades in the far-off galactic space.

In the initial years of discoveries and inventions the atmosphere was believed to have two layers, which were named as troposphere and stratosphere. Troposphere in Greek means ‘the sphere of change’. This layer is the most dynamic wherein clouds, winds, storms and other meteorological processes operate with impunity. Stratosphere is ‘sphere of layers’ and contains sub-layers of lighter gases such as helium and hydrogen. Between troposphere and stratosphere lies ‘tropopause’. This means ‘end of change’ because this layer was believed to mark cessation of temperature change. The tropopause is also the boundary or the intervening layer between the troposphere and stratosphere, which varies in height from about 16 km above sea level at the equator to about just 8 km above the poles.

When men reached higher altitudes, by various means – kites, balloons, manned cabins and so on, the realization dawned upon them about the impermanency of the constant temperature. The temperature started to rise above 35 km at which level the stratosphere comes to an end. The atmosphere above this zone was penetrated later by rockets. Above the stratosphere, at a height of about 48 km, the temperature rose to a maximum of –10° C, then dropped to –90° C at 80 km. This is ‘mesosphere’, the region where temperature rises and falls. Beyond mesosphere the mass is very meager. Though the air is very thin here, the scattering of air atoms steadily increases in temperature to an estimated 1000° C at 480 km and above. Hence, this region is called the ‘thermosphere’ or ‘the sphere of heat’. But the temperature that is referred to is not the ‘heat’ that is understood in the usual sense. It is, in fact, just the measure of the speed of the particles. Above 480 km lies the ‘exosphere’, which extends to as high as 1600 km and gradually merges into the interplanetary space, called ‘exosphere’.

The atmosphere is obviously made up of gases and the massive temperatures and heavy radiation up above can pull apart atoms or force them into new combinations. But, at such levels, the prevalent energy can take away the electrons from the atoms. When this happens, the atom is said to be ionized, and is called an 'ion', meaning 'traveller'. The process that converts a neutral atom into a positively charged one is called ionization.

The discovery of ions in the atmosphere came later with the experiments on wireless transmission. Radio signals (Morse code) were sent from Cornwall, England to Newfoundland, America across the Atlantic Ocean. This transmission left scientists dumbfounded, because radio waves travel only in straight line. But the distance from Cornwall and Newfoundland formed a curvature. This unusual behavior was explained by invoking a layer of charged particles situated high up in the atmosphere which reflected the radio waves. This layer was located in the year 1920, which has since been called the 'Kennelly-Heaviside layer'.

Edward Victor Appleton, a British physicist, discovered the Kennelly-Heaviside layer, which reflected back the radio waves by scrutinizing closely a strange phenomenon of fading radio transmission. Appleton wondered as to why the fading or the dying out of the signal took place. Musing over it, he decided the fading occurred because of interference of two versions of the same signal. Appleton reckoned that if the fading was to occur there has to be a signal, which directly hit the receiver that was released from a transmitter, and the other reached the receiver via a circuitous route by reflection from the upper atmosphere. This second wave was a delayed one and so was out of phase with the first one. In-phase waves are the ones where the two wave peaks are together, thus reinforcing each other. On the other hand, two waves are said to be out of phase when the trough of one wave cancels out the peak of the other wave. They thus interfere with each other, partly canceling each other out. This interference of out of phase waves causes the dying out or fading out of the signal. The understanding of this mechanism helped locate the height of the reflecting layer.

Appleton located this reflecting layer by sending signals of a particular wavelength, such that the direct signal completely cancelled the reflected one. This meant the two signals arrived at the receiver at directly opposite phases. Appleton knew the wavelength of signal and also the velocity at which the radio waves traveled. Thus, by calculating the difference in the distances that the two streams of waves traveled, Appleton determined the height of Kennelly-Heaviside layer, which turned out to be 104 km.

Appleton later found another strange phenomenon. He noticed that the radio signals generally faded during night. But, shortly before dawn the radio waves were not reflected by the Kennelly-Heaviside layer but were reflected back from still higher layers, which begin at a height of 224 km. These are also called ‘Appleton layers’.

Appleton had defined the most significant and important region of the atmosphere, the ionosphere. Robert Alexander Watson-Watt, the Scottish Physicist, introduced the term ‘ionosphere’ in the year 1930. The ionosphere includes mesosphere and thermosphere. But now it is divided into a number of other layers. From stratopause up to 104 km or more is the ‘D’ region. Above the ‘D’ region is the Kennelly–Heaviside layer, also called the ‘D layer’. Above the D layer, to a height of 224 km, is the ‘E region’. The E-region is an intermediate area relatively poor in ions. This region is then followed by the Appleton layers – the F_1 layer at 224 km and F_2 layer at 320 km. The F_1 layer is the richest in ions. The F_2 layer is significantly stronger only during daytime. Above the Appleton layers is the ‘F region’. All these diverse layers together make up the ionosphere. The characteristic feature of the ionosphere is its ability to conduct electricity.

Beyond ionosphere there is a vast, dark inter-galactic space that extends on and on into eternity composed of plasma.

Below the ionosphere, into our very own atmosphere, are the gases and in 1930s it was believed hydrogen and helium floated over the heavier gases in the stratosphere. This was the belief of Teisserenc de Bort. However, he was proved wrong by the air samples that were brought down by the Russian balloonists in the middle of the 1930s. The upper stratosphere was made up of oxygen and nitrogen. Troposphere, too, contained these gases. But there was reason to believe that there existed some unusual gases that gave off ‘airglow’. Night airglow is the feeble illumination of night sky even in the absence of moonlight.

What caused the feeble light to thinly illuminate the sky remained a mystery till it was understood that it came from ‘atomic oxygen’. Atomic oxygen is a single atom and not a combined two-atom molecule that we normally know. The spectral lines emanating from aurora also gave clues to understanding the airglow. The auroral spectral lines were found to be of 'atomic nitrogen'. The atomic oxygen and nitrogen are produced by the energetic radiation of the Sun. The radiation breaks down the molecules into single atoms. This suggestion came in 1931 from Sydney Chapman. This is one mechanism, out of many others, by which nature absorbs or weakens the harmful radiation before reaching Earth.

Chapman further elaborated that the airglow was caused by the recombination at night of atoms that are split apart by solar energy during the day. During the recombination process the atoms give up some of the energy they absorbed in splitting. Thus, the airglow is some kind of a delayed and very feeble return of sunlight in a new and specialized form.

Direct evidences of airglow were found by rocket experiments carried out in the 1950s. Spectroscopes carried by the rockets recorded the green lines of atomic oxygen most strongly at a height of 96 km. The red light of atomic nitrogen was strong at a height of 152 km. Slipher also found yellow lines in the airglow emitted by sodium. Lithium was also found, in 1958, to be contributing to the airglow.

The ionospheric irregularities can be monitored and studied with the help of radio beacons carried onboard satellites through yet another technique called the scintillation. Scintillation is a rapid change in the phase or amplitude or both of a radio signal as it passes through small-scale plasma density irregularities in the ionosphere. This technique is ground based, inexpensive, and highly economical. It yields information about the strength, spectrum and dynamical behavior of meter to sub-km scale wavelength of ionospheric irregularities.

The radio waves were produced and detected by the German physicist Heinrich Rudolf Hertz in 1887. He was generating an oscillating current from the spark of an induction coil when he detected radiation of extremely long wavelengths. These came to be called the radio waves. The radio waves served a purpose by providing indirect evidences that the Earth was flooded with charged particles. It was found that the radio waves generated by lightning traveled along the Earth's magnetic lines of force. These waves are called 'whistlers'. The German physicist Heinrich Barkhausen discovered whistlers during the course of World War I. He picked these radio waves as peculiarly odd whistling sounds. The radio waves could not follow the magnetic lines of force unless charged particles were present.

The discovery of radio waves opened a window to the far off galaxies, which later gave birth to radio astronomy. Radio astronomy has made many startling and exciting discoveries of far off space and galaxies. However, scintillation studies, based on rapid changes encountered in the phase and or amplitude changes of a radio signal, provide useful information and clues to small-scale plasma density irregularities in the ionosphere.

The upper regions of the Earth's atmosphere (namely the mesosphere and thermosphere) and ionosphere are strongly coupled to the lower and middle atmosphere by means of chemical, dynamic and electro-dynamic processes. The observed influence of the upward propagating gravity and planetary scale waves and atmospheric tides on the thermosphere and the ionosphere is an example of dynamical coupling. The giant global electrical circuit linking the lower atmosphere to the ionosphere and the magnetosphere provides an adequate link for the electrodynamic coupling, which warrants the studies into space weather conditions.

Why are the geomagnetic studies, particularly, exploration of the Earth’s magnetosphere so important? One compelling reason is that doing so helps us understand phenomena in the more distant universe, in particular the intricate web of plasma phenomena, magnetic fields and particle acceleration. But there also exists a practical angle: in a world increasingly dependent on electricity and electronics, the 'space weather' outside the atmosphere can have serious effects, in particular on human communications. Currently more than 200 communication satellites circle the Earth in synchronous orbit. A large magnetic storm can greatly increase the number of fast ions and electrons which hit those satellites; such ions and electrons are similar to the ones emitted by radioactive substances and can create serious problems. The simplest effect is an electric charge on the satellite, usually negative, raising its voltage to hundreds or even thousands of volts. Charging by itself has little effect on the satellite's operation, although on a scientific satellite it would seriously distort observations. However, if different parts of the satellite are charged to different voltages, the current between them can cause damage. Particles with higher energy can permanently degrade solar cells. Also, high-energy particles can penetrate the circuitry and cause either damage or false signals, which lead to unintended responses by the satellite. All these have occurred in the past.

Another effect of strong geomagnetic activity (and to lesser extent, of substorms) is a greater intensity of the electric current circulating between the Earth and distant space. These currents are associated with the polar aurora, and they flow from space into the auroral zone or the other way around. In big storms, not only is the magnetic disturbance more intense, but it also spreads further equatorwards, into more densely populated areas. This disturbance induces extra currents in the wires of the electrical power grid, creating a temporary overload. Serious overloads of this type can trigger circuit breakers and thus cause widespread 'power blackouts', and on occasions they have even destroyed power transformers.

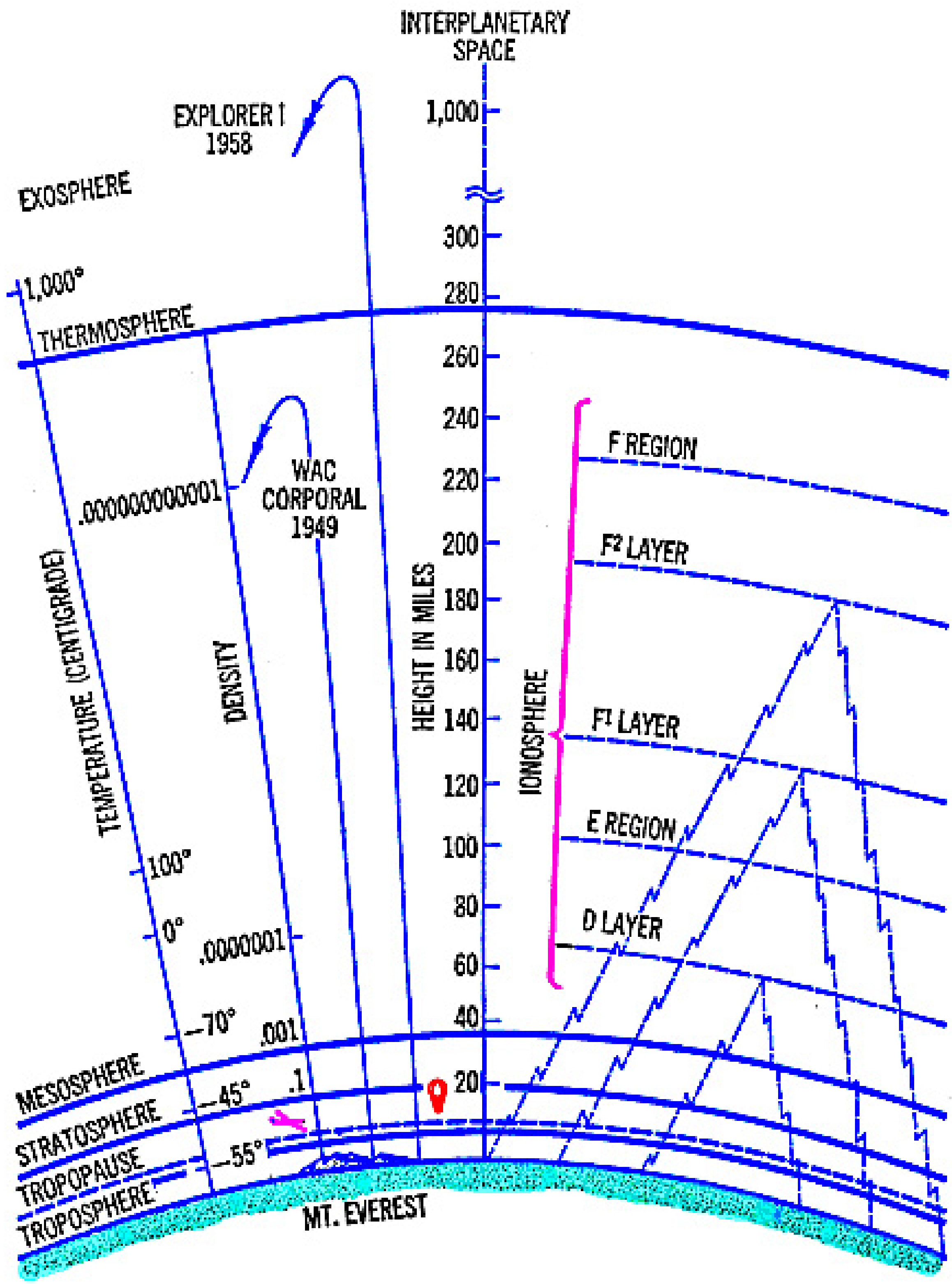

Figure from: Asimov Isaac, 1979, 'Asimov's guide to science', v.1, The physical sciences, Penguin books.