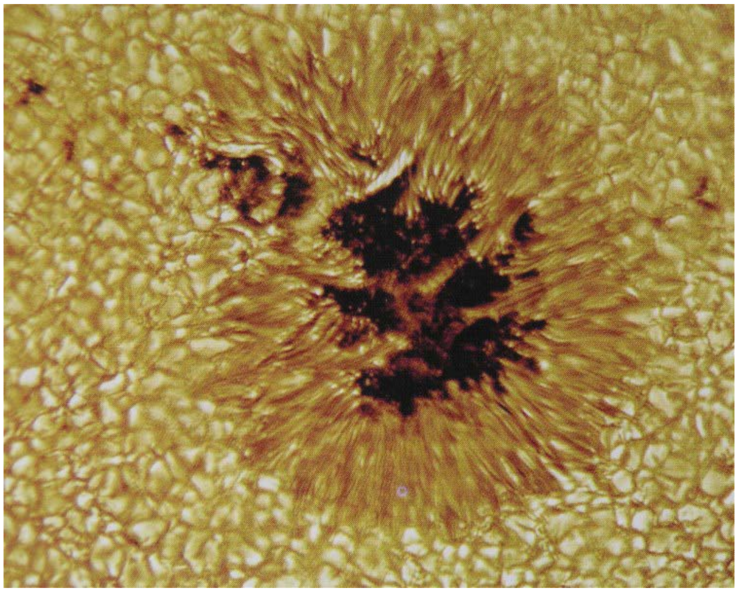
Solar Dynamics
Affecting
Skywave Communications



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1 Introduction

This is the first of a two part series studying High Frequency (HF) skywave radio communication. The two parts of the series are:

- Solar Dynamics Affecting Skywave Communications
- Regional and Long Distance Skywave Communications

The characteristics of the Earth's Ionosphere which affect HF radio communications are driven by the dynamics of the Sun. To understand the basics of skywave communications, one must first have an understanding of the Sun and the solar dynamics responsible for Earth's Ionosphere. These issues are covered in this part of the series. Part 2, looks at the characteristics of the Ionosphere which support both regional and long distance HF radio communications. With this foundation, the mechanisms of skywave propagation are discussed, including refraction, absorption, critical frequency, maximum usable frequency, maximum usable angle, skip distance, and propagation modes. Finally, the parameters used to measure the current conditions of the Sun and the Ionosphere, including Solar Flux, Boulder A and K indices, X-ray Flux, etc., are covered.

2 Structure of the Sun

The sun consists of six regions:

- The Sun's Core,
- Radiation Zone,
- Convection Zone,
- Photosphere,
- Chromosphere, and
- Corona.

These regions are shown in Figure 1

2.1 Core

The core is the central region of the Sun where thermal nuclear fusion of hydrogen into helium occurs. The central core occupies only about one quarter of the Sun's diameter, but contains two-thirds of the Sun's mass. The Core's density is 60 times that of solid rock.

2.2 Radiation Zone

The Radiation Zone is largest region of the Sun (about 55 % of its volume) through which the tremendous energy releases by nuclear fusion in the core radiates as x-rays and ultra violet light towards the Sun's surface. It can take 50 million years for the energy to flow from the core to the Sun's surface.

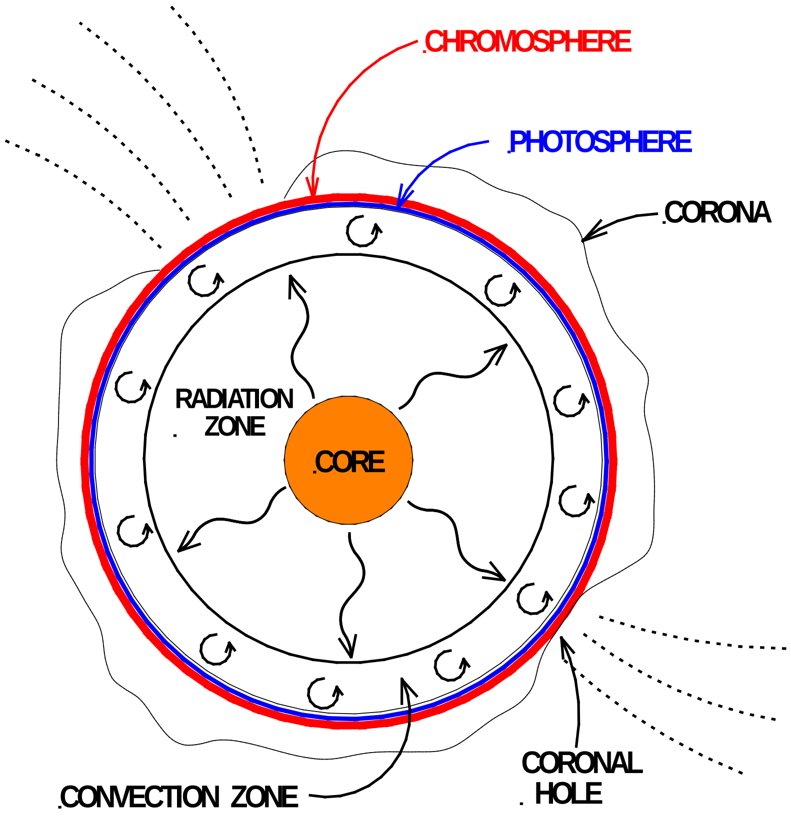

Figure 1 Structure of the Sun

2.3 Convection Zone

The Convection Zone is the transition layer in which hot gases from the Radiation Zone rise to the surface and cooler gases from the surface sink back toward the interior of the Sun. The Convection Zone makes up the outer 20% of the Sun. The Sun's magnetic field is created in the Convection Zone as the result of charged particles (hydrogen and helium nuclei) rising to the surface and sinking back into the interior.

2.4 Photosphere

The Photosphere is the deepest that we can see into the Sun. The Photosphere is only about 300 miles thick. However, at approximately 6,000 ^{o}C, the Photosphere gas is so hot that it is opaque giving the impression that the Sun has a solid surface. If the Earth's atmosphere were 6,000 ^{o}C, visibility would only be a couple of feet. Because of its opacity, we think of the Photosphere as the Sun's surface. Dark sunspots in the Photosphere appear black because of their cooler temperature, about 4,000 ^{o}C. Granulation forming the top of the Convective Zone is visible in the Photosphere picture shown below in Figure 2.

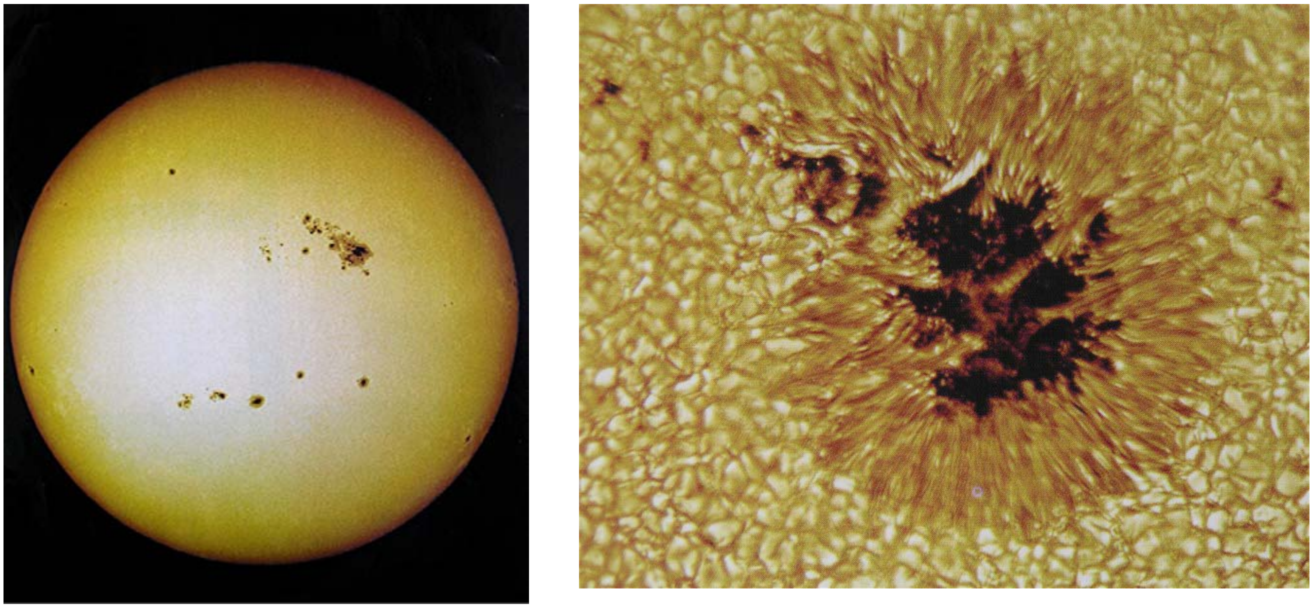

Figure 2 Photosphere

Figure 3   Chromosphere

2.5 Chromosphere

The Chromosphere is the turbulent region of the Sun just above the Photosphere. The Chromosphere is often regarded as the Sun's lower atmosphere. It is about 1,200 miles thick with a density that is only one ten thousands (1/10,000) that of the Photosphere. The density of the Chromosphere is much less than that of the Earth's sea level atmosphere. In fact, the density of the Chromosphere is so low that it is nearly a vacuum, yet it is a very violent place. The temperature of the Chromosphere rises sharply from 6,000 ^{o}C, at its boundary with the Photosphere, to nearly 200,000 ^{o}C at its outer edge.

Spicules, Plages, and Filaments occur in the Chromosphere, as shown in Figure 3.

Spicules are jets of gas hundreds of miles in diameter that shoot up thousands of miles above the Chromosphere. Spicules are not singular events. The Chromosphere is covered with countless billions of Spicules giving the Chromosphere its granular orangeous appearance shown in Figure 3.

Plages are bright active areas usually, but not always, associated with sunspots. They normally form before the sunspot appears and disappear after the sunspot vanishes. We think of sunspots as being the source of the energy responsible for creating the Earth's Ionosphere. However, plages are actually the source of most of the extreme ultra violate energy responsible for the Ionosphere. Since sunspots are easy to see and plages are not, sunspots serve as markers. If there are large numbers of sunspots visible on the Sun, then there are also large numbers of plages radiating vast amounts of extreme ultra violate energy, creating the relatively density upper Ionosphere on Earth needed for long distance HF communications. When there are few or no sunspots, there are few plages generating much less extreme ultra violate energy, the Earth's Ionosphere weakens, and long distance HF communications is poor.

Filaments are better known as prominences when seen on the edge of the Sun. A prominence is a huge plum of hot positively charged hydrogen gas ions (hydrogen atoms stripped of their electrons) suspended above the Chromosphere by the Sun's magnetic field. A prominence is shown in Figure 4 with a picture of the Earth inserted to show relative size. A prominence can last of months. When viewed on the face of the Sun, prominences appear as dark threads, as shown in Figure 3, which is why the name filaments.

Figure 4 An Arching Prominence (Filament)

The most violent events on the Sun are flares. A single flare can release as much energy as 10 million hydrogen bombs. A flare occurs when the energy in a twisted magnetic field knot is suddenly released as intense light and streams of particles. Flares can occur every hour or two when the solar surface is especially active. When the Sun is quiet there may be none for days or weeks.

2.6 Corona

The Corona is the wispy outer part of the Sun’s atmosphere shown below in Figure 5. It extents out more than a million miles from the Photosphere. The Corona is so thin that stars clearly shine through it when the bright disk of the Sun is blocked by a solar eclipse.

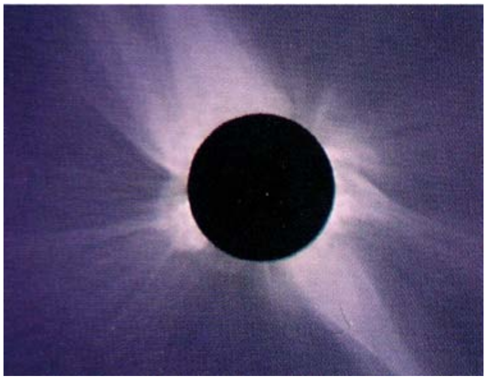

Figure 5 Corona observed during a solar eclipse.

3 The Sun’s Magnetic Field

The Sun’s magnetic field is formed by electrical currents flowing in the Convection Zone, near the Sun’s surface. The problem is that the Sun is a “hot ball of gas”. Consequently, its equator is revolving faster than its poles. A point on the Sun’s equator takes 27 days to rotate. A point at either pole takes 32 days. This differential rotational speed badly distorts the Sun’s magnetic field, while the Convection Zone twists it into knots as shown in Figure 6.

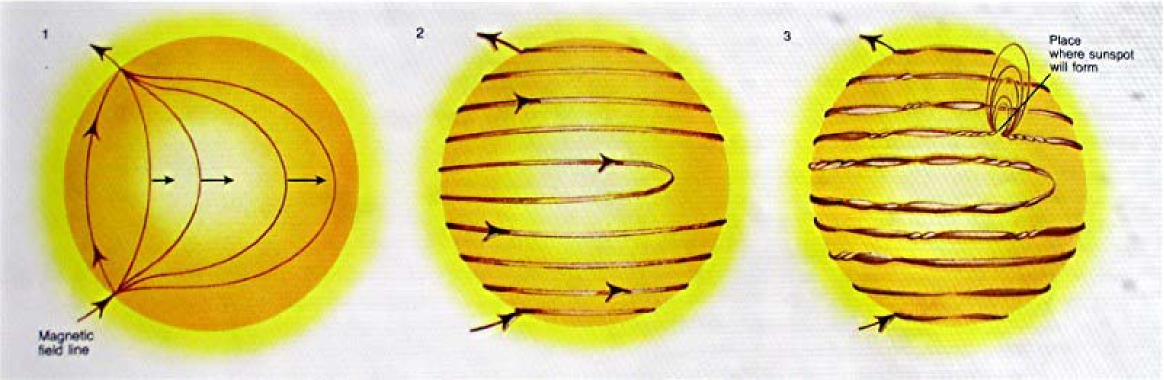

Figure 6 Solar Magnetic Field

At the beginning of a roughly 11 year cycle, the Sun's magnetic field is in a relatively uniform polar direction as shown by the field in the left hand picture of Figure 6. There may be few or no sunspots visible on the Sun. Since the equator is rotating faster than the poles, the magnetic field over time becomes wrapped around the Sun as shown in the middle picture. As more time passes, the magnetic field becomes twisted and knotted as shown on the right.

The strength of the Earth's magnetic field is 0.2 gauss, while the nominal strength of the Sun's magnetic field is about 1.0 gauss. However, in the twisted knotted sections of the Sun's magnetic field, the field strength can be more than a 1,000 gauss.

A pair of sunspots is formed when a section of twisted knotted magnetic field erupts through the Photosphere. Clusters of sunspots often occur as shown in Figure 7. A large sunspot may be five times larger than the Earth. The magnetic field associated with a sunspot is so intense that it prevents the usual flow of energy upward from the Convection Zone, making the Sun's surface cooler in the region of the sunspot. This accounts for the sunspot's dark appearance.

Figure 7 Sunspots in both the upper and lower hemispheres

Sunspots first appear in the higher latitudes of the Sun's upper and lower hemispheres (at 20 to 30^o latitude) as the magnetic field begins to wrap around the Sun. A specific pair of sunspots may last from a few hours to several weeks. More sunspots, progressing toward the Sun's equator, appear as the magnetic field becomes more twisted and knotted. Each pair of sunspots has a local magnetic field associated with it in the same direction as the magnetic field in its hemisphere. The direction of the sunspot magnetic fields in the upper hemisphere are in the opposite direction of those in the lower hemisphere. As the sunspots from the two hemispheres approach the equator, their magnetic fields cancel, the sunspots disappear, and the Sun's very convoluted magnetic field unwinds. The Sun's magnetic field again returns to a more uniform polar field, signaling the end of one 11 year solar cycle and the beginning of the next. However, in the process, the Sun's magnetic poles reverse. If the upper hemisphere pole was the north magnetic pole, it will now become the south magnetic pole for the next 11 year cycle. At the end of that cycle, it will again become the north magnetic pole. Thus the complete solar cycle for the Sun is approximately 22 years.

It should be noted that high latitude sunspots of the next cycle may begin to form while the sunspots of the previous cycle are still appearing near the equator. That is, sunspot cycles may or may not over lap.

The intense magnetic fields in the vicinity of sunspots are also responsible for the plages and solar flare that occur in the same area.

4 Solar Activity

The number of active regions (sunspots, plages, filaments, and flares) increase as the sunspot cycle reaches maximum.

- Plages are a major source of extreme ultra violet energy that ionizes the Earth's upper atmosphere forming the Ionosphere F layer.
- Suddenly disappearing filaments (prominences) eject large quantities of charged particles which disrupt the Earth's Ionosphere.
- Flares produce x-rays and eject large quantities of charged particles.

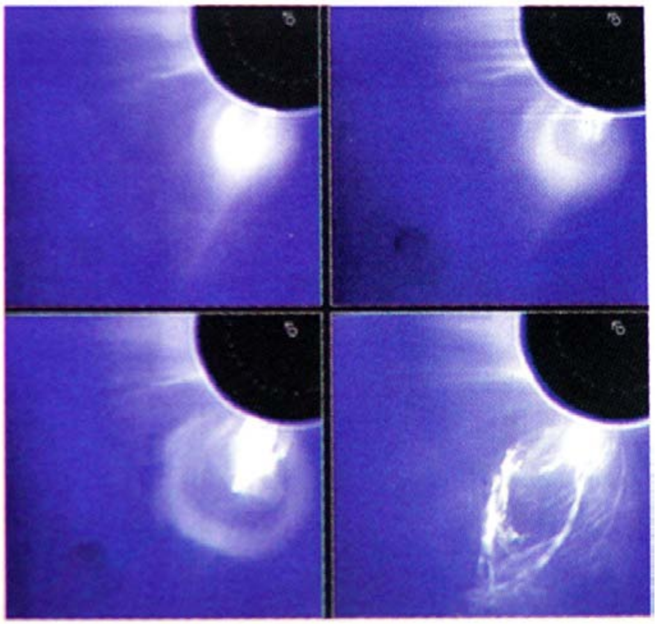

Figure 8 Time laps pictures of a solar flare

A solar flare is a large explosion on the Sun caused by a sudden release of magnetic energy. A solar flare generates an enormous amount of x-ray radiation which reaches Earth in 8 minutes. The x-rays heavily ionize the Ionosphere D layer. If the D layer ionization is great enough, all radio signals in the 160 through 40 meter amateur radio bands will be completely absorbed, while higher frequency signals may be absorbed or badly attenuated. Disruption in signal propagation can last from minutes to several hours depending on the size of the flare.

A solar flare also ejects large quantities of charged particles (protons). These particles take hours to several days to reach the Earth, depending upon their speed. When they reach the Earth they combine with the free electrons in the Ionosphere F layer, partially de-ionizing that layer. As a result, communications on the 20 through 6 meter amateur radio bands are disrupted, the higher frequency bands more so than the lower frequency bands. There may be little noticeable impact on 160 through 40 meter communications.

If a large solar flare occurs, we can expect the lower frequency amateur radio bands to be immediately affected, and the higher frequency bands to be disrupted several days later.

5 Coronal Holes

A coronal hole is a cooler region of the Corona. A coronal hole is associated with open magnetic field lines that extend out great distances from the Sun instead of folding back to the Sun's surface. Billions of tons of charged particles flow out from the Sun along these magnetic field lines. Coronal holes are the primary source for the solar winds.

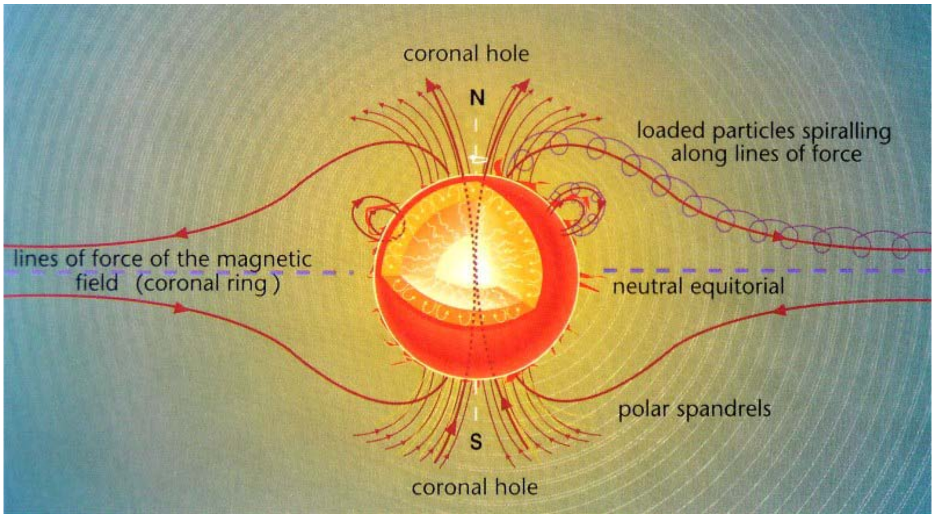

Figure 9 Coronal Holes

Solar winds flow out from the Sun over its entire surface. But solar ionized material pours out of the coronal holes much faster and in greater intensity than the background steady solar winds. These high speed solar winds flow out from the Sun much like water from a rotating lawn sprinkler as shown in Figure 10. A coronal hole and its associated high speed solar winds can last for months, periodically spraying the Earth with charged particles.

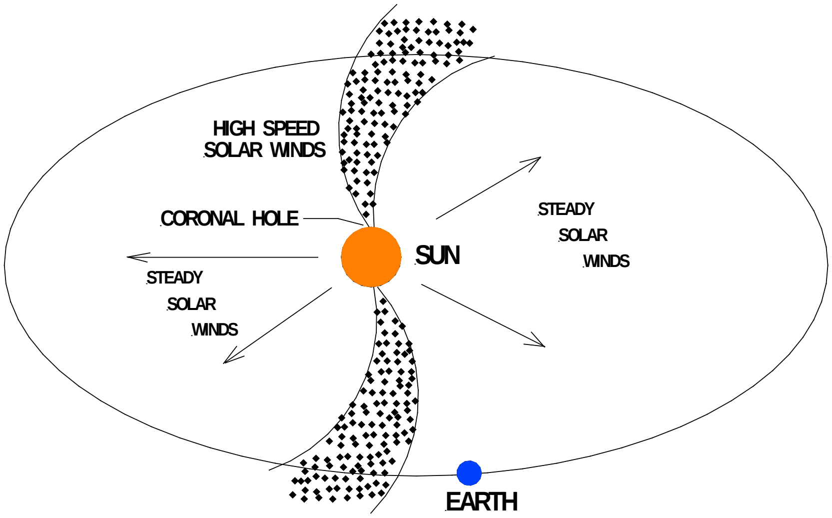

Figure 10 High speed streams in the solar wind.

6 Coronal Mass Ejection

Coronal mass ejections (CMEs) consists of huge quantities of matter that are explosively ejected from the Sun. Most ejections originate from active regions of the surface, such as groupings of sunspots, and are often associated with large flares. However, CMEs may also occur in quiet regions of the Sun, although in many cases the quiet region was recently active. The frequency of ejections depends on the phase of the solar cycle. 5 to 6 CMEs can occur per day during solar maximum. During solar minimum the frequency may be only one every other day.

When the ejection is directed toward the Earth, the traveling mass of energetic particles creates a geomagnetic storm upon impact with the Earth's magnetic field. The resulting disruption in the magnetic field causes particularly strong auroras in large regions around Earth's magnetic poles.

7 The Earth's Magnetic Field

The Earth's magnetic field should be a nice dipole field as shown in Figure 11. But instead, the solar winds and Coronal Mass Ejections badly distort the magnetic field. The part of the Earth's magnetic field facing the Sun is compressed while the rear facing part is stretched out into a very long magnetic field trail as shown in Figure 12.

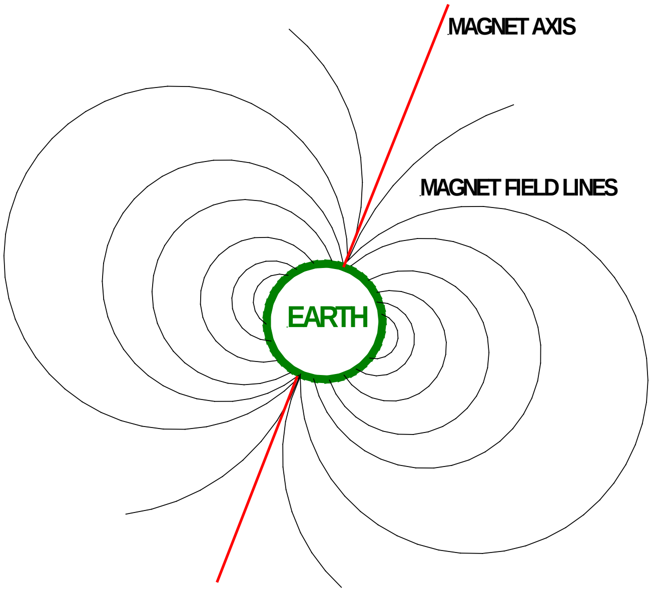

Figure 11 Ideal Earth Magnetic Field

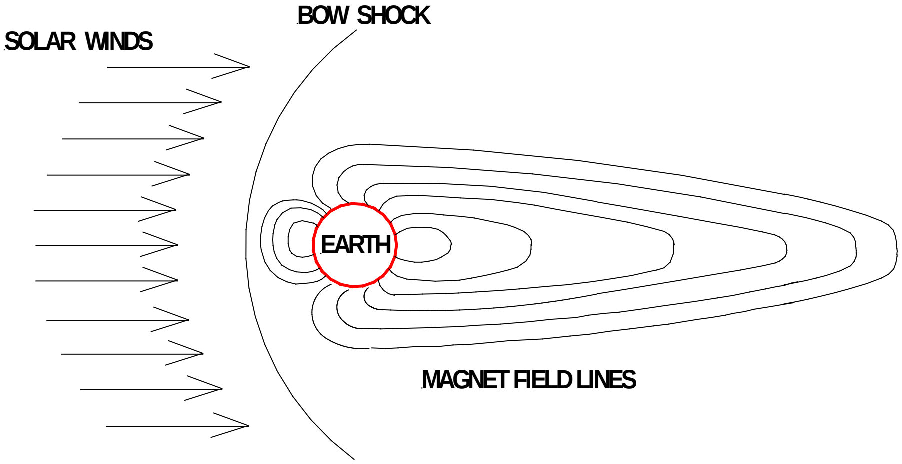

Figure 12   Earth's Actual Magnetic Field

The Earth's magnetic field lines are parallel to the Earth's surface over the equator. The magnetic field thus protects the equatorial region of the Earth, and that part of the Ionosphere, from the solar wind and CME particles. The magnetic field lines at the poles are vertical. Consequently, solar wind and CME particles flow down the magnetic field lines deep into the polar atmosphere and Ionosphere creating the aurora. The poles are the Earth's magnetic field garbage pits.

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