Why Observe The Earth's Magnetic Field ?

G. K. Rangarajan

Indian Institute Of Geomagnetism, Bombay 400 005

"There are materials which attract iron and have a directive property to indicate North". Ancient Indians certainly knew this. The Chinese have recorded knowledge of it even two thousand years before Christ! But the fact that the planet Earth itself is one huge magnet with a pervasive geomagnetic field was emphasised only in 1600 A.D. by William Gilbert, the royal physician of the British Empire. From stray observations of the compass needle in different parts of the globe, he could ascertain that the Earth's magnetic field is equivalent, to a large extent, to that of a bar magnet – placed slightly off- centre in its interior. Subsequent painstaking measurements carried out clearly indicated some fascinating features: there are changes in the strength and direction of the field spanning from several hundreds of years to regular smooth daily variations. In addition there are occasional violent outbursts of short duration which appeared to be closely linked to the Sun. These discoveries whetted the curiosity of the inquisitive mind to unravel the causative agents and look for inter-relationships between the Earth, the Sun and other planets or satellites like Moon and use this knowledge for the benefit of mankind.

When you ask a mountaineer why he climbs the hills he would naturally reply: "Because it is there!" In a similar fashion, one studies the intricacies of the changes in the geomagnetic field not only because they encompass several time scales from few million years to even a fraction of a second in several spectral bands but also because each band of frequencies is goldmine of information indicative of various causative mechanisms with sources in the Earth's interior, near space or far space environment. In this article, we examine a few inportant frequency bands of geomagnetic field oscillations to justify an answer to the question "Why should we monitor the changes in the Earth's magnetic field?"

Polarity Reversals and Palaeomagnetism

Variations of the geomagnetic field with periodicities of several thousands to several million years are related to reversals of the direction of the Earth's field. The branch dealing with the magnetic field of the geological past is called Palaeomagnetism. The more recent historical past are covered under Archaeomagnetism.

An intriguing property is that the magnetisable materials in a molten lava, when cooled below a critical temperature – the Curie temperature – acquire the strength and direction of the Earth's magneic field prevailing during the time of the solidification and leave an identifiable imprint of the past geomagnetic field in the rock samples. Careful processing of the sample for detecting the field and the concurrent determination of the age of the rock enables the recreation of the location of the equivalent bar magnet at the Earth's centre over several epochs: say present, 50 million years ago, 100, 200, 300 or 500 million years ago etc. This reconstruction of the pole location through the remnant magnetisation in rocks in different parts of the world provided one of the strongest supports to the modern theory of Plate

Tectonics. According to this, the upper layers (~ 70 to 100 km) of the Earth are broken into several major plates moving independently floating on the molten fluid below. Some collide with each other causing Earth tremors, others drift apart creating ocean ridges and trenches and still others slide past. The rise of the Himalayas is attributed to the northward movement of the Indian plate being resisted by the Tibetan plate.

From palaeomagnetic studies, it appears that the Earth's magnetic field has flipped in its direction several times in the past, each flip being termed a "Polarity Reversal". In contrast to the duration of one type of polarity before reversal, of few to several million years, the process of actual reversal is much smaller, only a few thousand years. Magnetic fields of the recent past are measured in a similar fashion from the embedded signatures in bricks, kilns and potteries giving informations on the field status in historical times, as the clay in the process of being converted retains the ambient magnetic field of that epoch. The magnetic moment of the Earth's field is decreasing monotonically and if the present rate continues we will be in an epoch of no geomagnetic field in about 1200 years from now. It is different to contemplate the likely hazards of outerspace radiation if the protective shield of geomagnetism is totally withdrawn.

Secular variation and Geodynamo

The slowly changing geomagnetic field in the time frame of hundreds of years is called its Secular Variation. The study indicates that the principal mechanisms responsible for the source of the Earth's main magnetic field - attributed to a Geodynamo are transitory in nature and not constant. Just as the turbines in a hydroelectric power station moving in the presence of strong permanent magnet due to the falling water produce electric currents, molten electricity conducting material in the outer core of the Earth moving due to convection set up by radioactive heating generates electric currents and consequently also the associated magnetic field. The retardation/acceleration of this convection due to the interaction at the core-mantle boundary leads to the observed secular changes in the magnetic field. Monitoring the secular change at several strategic locations on the globe can thus provide inputs to understand the electrodynamics of the Earth's interior which is otherwise inaccessible. Just imagine the advantages of sitting on the Earth's surface to fathom the mysteries of the deep interior using only a tiny magnet! It is, of course, of paramount importance that the recording station continues in an undisturbed environment for as long as possible. India has an excellent tradition in this regard with its oldest magnetic observatory at Alibag near Bombay completing 150 years.

Sun as a primary cause for 'Magnetic Storms'

As we come to quasi-periodic fluctuations of a few years and less, it becomes evident that the responsible generators are located on the distant Sun. In the 18th and 19th centuries, astronomers could locate dark (relatively cooler) regions on the Sun called Sunspots. Their count on the visible solar disc waxed and waned in a cyclic fashion with a periodicity of about 11 years. The number of days in a year when the observed geomagnetic field was disturbed moved in close harmony with the sunspot numbers. Early 20th century scientists came out with the hypothesis that occasional bursts of plasma from some active centres on the Sun was responsible for the observed geomagnetic disturbances. Dr. Nanabhai Moos, the first Indian Director of the Colaba and Alibag Observatories (the predecessor of the Indian Institute of Geomagnetism) is one of the pioneers on these studies and his phenomenal insight into the geomagnetic disturbance phenomena have been appreciated globally as truly "monumental". In contrast to the cyclonic storms in meteorology which are highly localised, geomagnetic storms are global phenomena recorded everywhere on the Earth, albeit with different magnitudes.

Charting the course of the movements of the sunspots – which are also regions of very strong magnetic fields – across the solar disc we find that they have a cyclicity of about 27 days associated with the solar rotation. If there is a solar centre of enhanced activity responsible for a geomagnetic disturbance, then there is a strong possibility of the same repeating after a lag of about 27 days.

The dense network of global magnetic observatories, among which the Indian chain of 12 stations holds a pride of place, has been an invaluable source to understand the intricacies of the solar terrestrial relationships. Advent of the spacecraft since 1957 has helped with observations in the interplanetary space clearly confirming the earlier hypotheses of the solar sources for magnetic storms. The outer region of the Sun – The solar Corona – is the source of the persistent plasma emission from the Sun called the Solar Wind. The solar wind traversing the interplanetary space at sufficiently high speed (300 to 1000 km/sec) meets the outwardly expanding geomagnetic field on the sunward side generates a barrier and confines the Earth's magnetic field inside a cavity – the Magnetosphere. The magnetospheric volume is in dynamic equilibrium with the solar wind. As the solar wind and the embedded solar magnetic field change with solar activity, a complex interplay in the near and far space electrical environment of the Earth takes place leading to a plethora of geomagnetic signatures. Observations of these ground magnetic field fluctuations and their correspondence with the electrical and plasma parameters in the upper atmosphere, magnetosphere and the interplanetary space enables us to work out specific cause-and-effect sequences. Once established firmly, these links provide valuable inputs as a diagnostic tool of the outer space normally not accessible. Let's not forget that drastic changes in the environmental conditions can degrade and disrupt the functioning of sophisticated electronic equipment on board satellites, either civilian ones used for television, telecommunications etc. or the military ones used in espionage and so it is better to be forewarned.

Whenever there is a magnetic storm, the electrical state of the upper atmosphere particularly in the regions from where radio waves are reflected (100 to 500 km) get violently disrupted. Short-wave radio communication deteriorates leading to fade-outs. The digital data transmission between ground and satellite also gets bogged down by serious errors. There can be temporary loss of tracking the satellite in orbit during these intervals. At high latitudes, severe magnetic disturbances can cause electrical power shut-down and the long gas/oil pipelines (like the ones in Alaska) can generate enormous voltages leading to fatal consequences unless protective measures are taken. It is an irony that the state funding for researches in Geomagnetism which was on a steady decline all over the world received a major spurt following the heavy damage caused to spacecrafts, satellites and power stations during the severe geomagnetic storm of March 13- 14, 1989.

Tie-up of the correlations between selective features on the Sun and the changes in surface magnetic field enables us to predict the possibility of occurrence of violent geomagnetic disturbances. Also, when the relationships stand the test of time, we can infer the state of the Sun, the solar wind and the interplanetary space for periods in the past when no spacecrafts were in orbit. A typical example of the use of the uninterrupted long series of geomagnetic observations was provided when a scientist attempted to detect the influence of the passage of Comet Halley in 1986 through the Earth's magnetosphere in the night side. To check his findings and confirm his results he needed geomagnetic data from world observatories which functioned 76 years earlier as the previous passage of the comet was in 1910. Alibag was one of the few global stations useful in this quest with records dating back to 1910.

E.M. Waves from the Sun and the quiet-time geomagnetic field

In the foregoing discussions, we have emphasised on the particle or plasma radiation from the active Sun. In addition, we get electromagnetic waves encompassing the familiar band of frequencies— ultra-violet, through the visible light to the infra-red. The UV and X-ray emissions are capable of splitting the neutral atmospheric constituents into ions and electrons leaving the atmosphere in an ionised state at altitudes above 60 km. where the gas density is not too large for collision processes to restore neutrality. This ionised air (particularly in the height region of 100-140 km) moving across the Earth's main magnetic field once again acts as a dynamo, generating electric currents during the daytime. The movement of the air is caused largely by tidal winds due to solar heating and gravitational pull due to the Moon. As the Earth rotates under this overhead daytime current system, a smoothly varying magnetic field is produced at every longitude whose magnitude and shape is a function of the station location, time of the day and season of the year. They offer clues of the vagaries of the upper atmosphere, particularly the day-to-day and seasonal changes in its electrical state in different regions. Close to the equator where the vertical component of the geomagnetic field vanishes, this current gets enhanced abnormally during daytime. In India this region is close to the tip of the peninsula. Establishment of the rocket launching facility at Thumba near Trivandrum in 1963 was motivated for the studies in ionospheric physics related to this zone with in-situ experiments.

Applications and modern trends

Despite the fact that Geomagnetism as a science was initially pursued more as an intellectual exercise, its study over the years has been responsible for many innovative technologies in instrumentation to detect weaker and weaker magnetic fields. Today, magnetometers based on superconducting materials can detect fluctuations of the order of one in a million with astounding accuracy. This has led to a new branch of application called Biomagnetism. In the course of time, it is hoped to have the health check and diagnosis of human ailments based only on passive magnetic measurements. Magnetotherapy is, nowadays, an accepted alternative for several physiological problems.

Faraday's fundamental law of physics that a fluctuating magnetic field will induce currents in a neighbouring conducting medium (and hence, generate an associated magnetic field) has been used extensively in Geomagnetism in recent times to decipher the nature of the electrical conductivity of the subsurface geological structures. The fact that the depth of penetration of the inducing field is inversely related to the frequency of fluctuations enables us to probe different layers beneath the Earth using suitable recording equipment to cover various frequency bands. Detection of sedimentary basins and oil bearing structures have been attempted with magnetic methods as initial probes at costs far less than the seismic methods. Ground water location could also be detected by suitable magnetic/electrical methods.

Another enigmatic field of research is the influence of geomagnetic activity on the weather and climate. Though most of the currents associated with the geomagnetic field flow at altitudes far above the regions which control the weather, intriguing results have emanated from the studies of the solar features, geomagnetic activity and meteorological parameters like the atmospheric circulation patterns, drought conditions, rainfall, glaciation etc. As it is unimaginable that solar activity can provide the requisite amount of energy for the meteorological changes, scientists attempt to identify some forms of catalyst that can trigger large scale transfer of the energy from the Sun and the interplanetary space through the upper atmosphere to the lower altitude regions.

In day-to-day life also, the geomagnetic field plays its part. The magnetic compass is still a must in the trekker's kit, on board aircrafts, rockets and missiles. Magnetic field is used to orient the dish antennas for satellite signals, for studies in migration of birds and even occasionally for settlement of insurance claims in case of air accidents.

The more one delves on this esoteric but useful topic, the more are the unsolved problems that crop up. The pace of research in this branch is really hectic with several specialised international organisations, exclusive scientific journals and sophisticated scientific laboratories all dedicated to this and playing leading roles. Spacecrafts and satellites have been amassing voluminous data 'in-situ' awaiting investigations.

As the Earth is but an ordinary planet of the solar system and as the Sun is but an insignificant star in the milky way galaxy it is the fond hope of geomagneticians that their scientific quest will pave way for a better understanding of the entire Universe, not just this planet Earth.