Earth’s Ionosphere, Magnetosphere, Sun-Earth interaction and Space Weather

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Contents

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Thermosphere - Ionosphere

The Earth's atmosphere corotates with it. It is categorized into five regions that are t*roposphere* (0-15 km), *stratosphere* (15-50 km), *mesosphere* (50-90 km), *thermosphere* (90-400 km) and *exosphere* higher above. These separation between these regions is not so well defined, but by broad separation boundaries namely *tropopause* (170K), *stratopause*(260K), and *mesopause* (150K) respectively. Overall, about 99.9% of the mass of the atmosphere is concentrated below 90 km, while only one part in 10^5 is distributed above it. The upper atmospheric part of the earth's environment which is very relevant from the point of view of Sun-Earth Connections and space weather, is the *thermosphere*. The thermosphere extends from the coldest (~150K i.e. mesopause) to the hottest (>1000K i.e. exobase) part of the atmosphere. The main constituents of this medium are the atomic & molecular oxygen ($O;O_2$) and molecular nitrogen (N_2).

One very important part of Earth's atmosphere that is collocated with thermosphere and plays a very significant role in its energetics and dynamics is known as Ionosphere. Ionosphere essentially describes the atmosphere that is ionised and characterised by collective behaviour of plasma. Like in the case of neutral atmosphere, the ionosphere is also divided into regions namely D, E and F. During specific conditions, distinct ledges of ionisation get formed within F layer also during daytime which are known as F1 and F2. As mentioned earlier, the boundaries of these layers gradually merge into each other. At around 90 km altitude D region transitions to E region while the transition from E to F region is believed to take place at around 150 km. The lower extent of the ionosphere is often taken to be at ~ 50 km [Figure 1].

The ionisation is produced in the earth's atmosphere by a wide spectrum of solar radiation. During solar maximum, the solar X-radiation of roughly 1-8 °A provide the major source of ionisation for the D-layer. H-Ly α 1216 °A absorbed by NO is the important ionising radiation for D-layer during solar minimum. Apart from this, there is a cosmic ray contribution too in the D-region ionisation. The 796- 1027°A band in UV radiation provides most of the E-region ionisation. Another contribution to E-region ionisation comes from solar X-radiation in the range 8-140 °A. The F-region ionisation is also provided by solar UV radiation whose upper limit is approximately around 796 °A roughly in the range 140-796 °A. The E-region and lower F-region are almost devoid of negative ions. For instance NO+, O2 + are the important ions below ~150 km. While above 150 km the plasma is dominated by O+ ions. In lower altitude regions, where molecular ions dominate, the plasma density is drastically reduced at night due to faster dissociative recombination reactions. The plasma higher above (H+, O+ ions) remains throughout the night. The processes of photo-ionisation, dissociative recombination and radiative recombination are replete in these regions.

It has been found that in the ionosphere, the electrons at two different altitude regions follow different loss mechanisms. Below 150 km, the molecular dissociative recombinations determine the electron loss rate, while at greater heights ion-molecule interchange reactions determine the loss rate of electrons. The transition between these two regions occurs in the F-region at about 160-200 km. When this transition region coincides with the level at which the F-region ionisation production is maximum, the former splits into F1 and F2 layers.

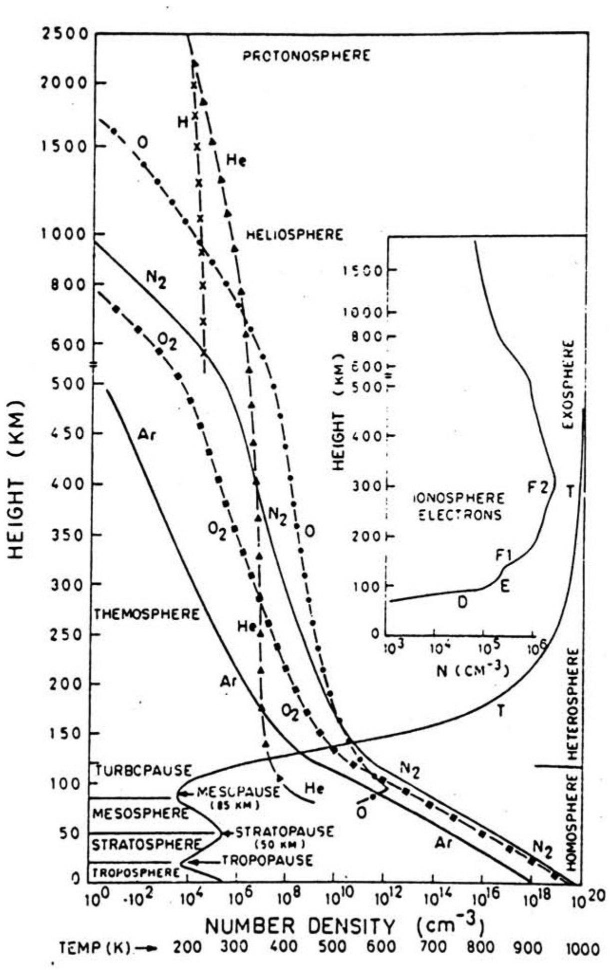

Figure 1 : Altitude variation of the thermal and composition structure of the atmosphere

Earth’s Magnetosphere

According to the classical definition, the earth’s magnetosphere is a vast magnetic cavity in which the earth resides. The nature of the magnetic field primarily is dipolar. The source of this magnetic field is believed to be a giant dynamo inside the core of the earth.

Interestingly, the dipole field behaves as a compressible fluid and on interacting with the solar wind gets distorted. The solar wind is known to compress the geomagnetic field to about 10RE in the sunward side and drags it to several hundred earth radii (RE) in the nightside. The cavity boundary i.e. the magnetopause, is in dynamic equilibrium. At the same time, it is highly variable due to the continuously altering dynamic pressure exerted by the solar wind. The vast region inside the magnetopause is the 'magnetosphere'. In our solar system except for Mars and Venus, which do not have intrinsic magnetic fields, all the planets have magnetospheres. The outer boundary of the magnetosphere is called the magnetopause, and it separates the domains of the planetary magnetic field and the solar wind that blows outside it. Its location is determined by the pressure balance between the solar wind and the planetary magnetic field.

On an average day Earth's magnetopause at local noon (subsolar point) crosses the equatorial plane at ~10RE (average Earth radius, ~6367 km), and at ~ 20RE in the dawn and dusk sectors. In the antisunward direction, the magnetosphere has a magnetic tail. The geomagnetic tail extends beyond 100 RE. As the solar wind flows with velocity significantly larger than the acoustic limits during solar events, its flow leads to the generation of a forward shock that propagates ahead of the solar wind. The region behind the shock wave is called magnetosheath and it extends to the magnetopause. The magnetosheath is a turbulent region permeated by large amplitude waves and hot particles that have been created in the shock formation.

Inside the magnetosphere, the famous Van Allen radiation belts, named after their discoverer, James Van Allen, are found. These are divided into inner (ionosphere to ~4–5RE) and outer (~4–5RE to the magnetopause) radiation belts. The inner radiation belt energetic particles come from neutrons produced by cosmic rays that bombard the planet's atmosphere. The source of the outer radiation belt particles is tied to solar wind and auroral disturbances which are dynamic.

However, it is important to mention that the dipolar field of the magnetosphere is only one component of the field. In reality there are other important components owing to the electrical currents replete in the ionosphere and magnetosphere. The highly energetic solar wind plasma being unable to directly penetrate deep into the magnetosphere through magnetopause, sweeps around the earth. In this process, it surrounds the cavity by dragging the field along in the antisunward direction resulting in a long active tail like structure, appropriately called the magnetotail. Figure(2) schematically illustrates the interaction of solar wind with earth's atmosphere.

During the solar wind magnetospheric interactions, a preferential flow of plasma, energy and momentum takes place from the solar wind to the magnetosphere. Two fundamental processes had been thought to be providing the conversion mechanism for energy stored in the magnetic field, are the viscous interaction and magnetic reconnection or Flux Transfer Events (FTE). The energy transfer efficiency during a reconnection event is of the order of 10% while it is only 1% for viscous interaction through micro instabilities and their resonant interaction in a collisionless plasma during intense northward IMF phases. Magnetic reconnection is thought to be by far the most effective mechanism for the energy exchange between the solar wind plasma and terrestrial atmosphere.

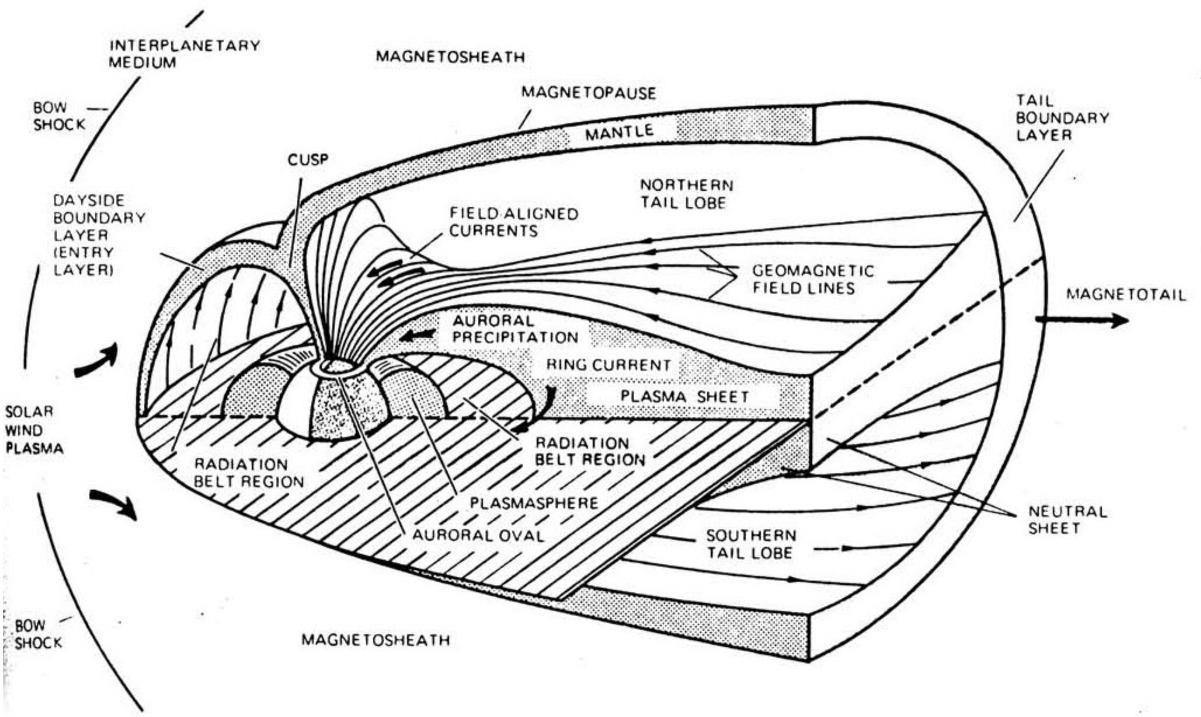

Figure 2: Schematics of the magnetosphere *(Courtesy J. Roederer)*

Sun as a Source of Energetic Plasma

Sun's outer atmosphere, the corona, is the source of the solar wind. Some of the space missions like the Solar Maximum Mission (SMM) has concentrated on these aspects. The measurements made on the total solar irradiance and its variation over 11 year period encompassing solar cycle No. 21 and 22; by the Active Cavity Radiometer Irradiance Monitor (ACRIM) onboard the SMM has shown that the solar magnetic activity has a positive correlation with the number of sunspots and bright faculae and plages in the solar disk. Some more results on the measurements made by the 'Earth Radiation Budget' experiment onboard Nimbus-7 satellite have been summarized by Hoyt [1993] supporting the above results. Apart from irradiance variations, there are important observations and also questions about the acceleration of transient solar wind arising from explosive solar events called 'Coronal mass ejections'(CMEs) and flares.

The CME associated solar flares can generate impulsive bursts of energetic particles, hard X-rays and gamma rays. In fact, CMEs are the primary sources of large fluxes of energetic particles. The CMEs are distinct structures of solar plasma that traverse through interplanetary space opening and carrying out magnetic fields from the solar corona. This magnetic field is referred as the Interplanetary magnetic field (IMF). The IMF is generated, primarily by the magnetic dynamo inside the sun; and is directed radially inward or outward near the sun. In this context, the each CME projected towards earth brings energetic solar plasma and magnetic field towards Earth. Typically the shock front arrives first. The magnetosphere interacts with this incoming shock and solar plasma producing geomagnetic activity on earth’s atmosphere after some time delay. The severity of the disturbance depends upon the polarity of north-south component of the IMF as well as, the velocity of the incoming solar wind. However, all storm events are not associated with solar flares. It is CMEs, not flares, that are now considered to be linked with observed phases of geomagnetic activity.

The energy, in most of the CMEs, is associated mainly with the ejected plasma. The kinetic energies range from 1022 to 1024 Joule. Current efforts are focussed on studies indicating the topology of ejected magnetic fields. Solar wind mainly consists of protons (H+) ~ 95%, ~4% of Alpha particles (He++) and ~1% of minor ions, of which carbon, nitrogen, oxygen, neon, magnesium, silicon and iron dominate. Solar wind velocity in the ecliptic plane is measured in the range of 300 to 600 km/s which under some very active space weather conditions can even exceed 1000 km/s. The density of solar wind particles is between 1-10 /cm3 and the kinetic temperature of particles is in the range from 10^4 - 10^6 K. The charge energy mass (CHEM) instrument aboard AMPTE spacecraft has provided number of composition measurement of high speed solar winds.

The important energetic coupling between the solar wind and the earth’s atmosphere is facilitated by the interaction of the IMF with the geomagnetic field/magnetosphere. The interplanetary magnetic field remains ‘frozen’ in the solar wind plasma by its very high electrical conductivity, and as the solar wind plasma velocity, away from the sun, becomes faster than the Alfven speed, the solar wind and its ‘frozen in’ magnetic field cannot contract back to the sun and it spreads out into the interplanetary medium. This spiralling field and plasma then interact with planetary atmospheres and their respective magnetic fields. Out into the space, the field, because of the motion/rotation of the sun, gets wrapped around at an angle in the form of an Archimedean spiral or a Ballerina’s skirt. Figure(3) depicts this special field orientation of magnetic field associated with Sun. The total amount of magnetic flux extending into the interplanetary space along with the solar plasma is quite variable. Analyses have indicated a substantial (~ 60%) variation in the IMF magnitude. Though, the instantaneous magnetic field directions deviate significantly from the ecliptic plane, on an average, the IMF lies in the ecliptic plane. The more fundamental questions regarding the origin and time evolution of IMF at the solar surface are beyond the scope of present discussion.

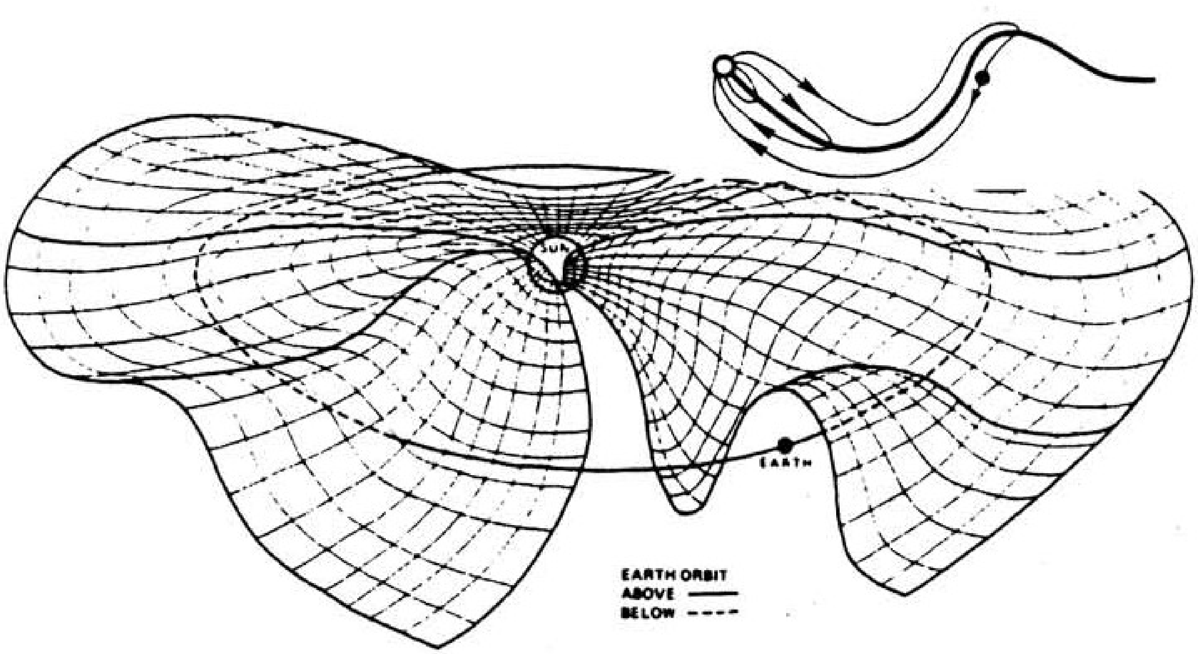

Figure 3: Three dimensional sketch of the solar equatorial current sheet and associated magnetic field lines *(Courtesy S.I.Akasofu)*

Interaction of Earth's Magnetosphere with the Solar Wind

The earth crosses in and out of the solar wind associated interplanetary magnetic field sectors as the sun rotates throwing highly energetic plasma from its corona. *S*trong associations had been shown between the initiation of geomagnetic storms and the magnetic clouds associated with the ejected plasma or the solar wind. Some very important results had been arrived at by the study of statistical correlations between source parameters characterizing earth's magnetosphere and some of the interplanetary fields (eg. IMF *Bz* component).

Magnetic Reconnection and Flux Transfer Events

Magnetic reconnection processes are essentially the magneto hydrodynamic interaction between the 'frozen in' field associated with the solar wind plasma and the geomagnetic field at the magnetopause. This interaction causes influx of energy and mass to the earth's atmosphere. As the incoming solar wind plasma impinges on the magnetosphere and compresses it, in some regions the solar wind (SW) associated IMF and magnetospheric field (antiparallel to each other) become so close that the geomagnetic field diffuses through the SW plasma and gets connected with IMF (*Bz* component). The newly reconnected field lines (flux tubes) move away from each other joining the general solar wind flow in the antisunward side, allowing the solar wind plasma to enter into the magnetosphere and to the ionosphere lower below. These reconnected field lines are swept back into the geomagnetic tail, where a second reconnection process takes place, producing field lines which are closed again and subsequently convect back towards earth. This, accelerates simultaneously (Fermi acceleration) the plasma or the flux associated with the closed field lines. Figure(4) depicts this process in a simplistic way. Usually the reconnection and the Flux Transfer Events (FTE's) are a short lived phenomena, the duration being decided by the kinetic processes and large scale dynamics. On the whole the magnetic reconnection and FTE's are quite complex, as revealed by the satellite missions and are extremely important in the investigation of magnetosphere-ionosphere-thermosphere system. As these are threaded by the same magnetic field lines, large amount of momentum and energy is exchanged among them during geomagnetically disturbed periods. Some of this energy is directly transferred to the ionosphere over polar latitudes through cusp regions and also via field aligned currents

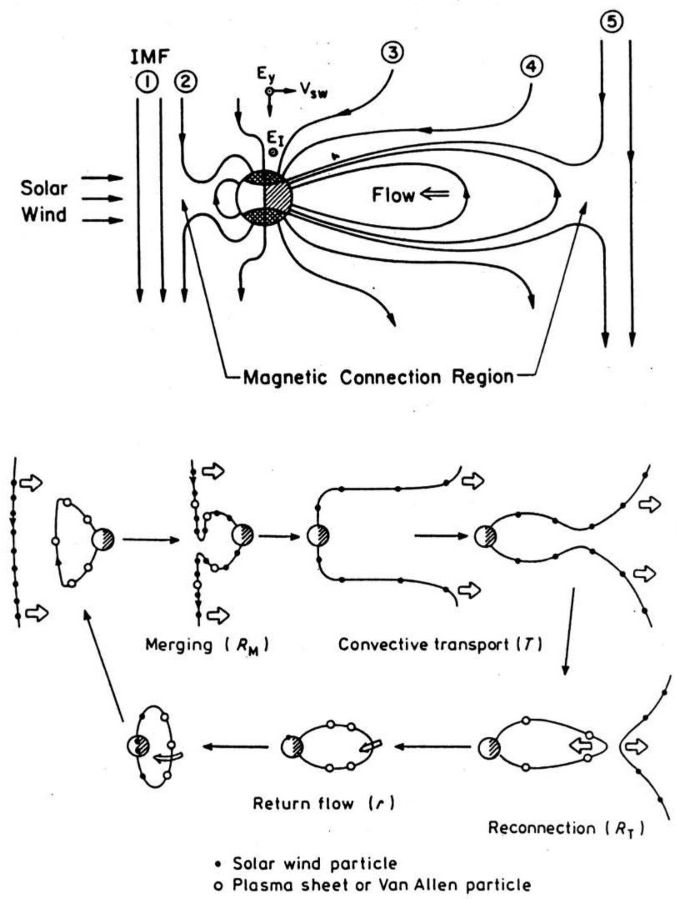

Figure 4: History of the field line after reconnection with IMF Bz on sunwardside and subsequent convection anti sunwardside *(Akasofu 1973)*

Space Weather

The Earth's outer magnetosphere is sometimes quiet, sometimes stormy, like the weather in the lower atmosphere of Earth. Therefore, a term 'Space Weather" is coined to define the state of the conditions on the Sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health and can potentially cause a variety of socioeconomic losses. But unlike terrestrial weather, 'space weather' is driven by electrical forces powered by the enhanced solar wind connected to a variety of highly energetic processes on the Sun e.g. solar flares and coronal mass ejections (CME). Several ground based and advanced satellite observations of global ionospheric, thermospheric, plasmaspheric and magnetospheric processes have provided an important framework to understand the true global nature of the geomagnetic disturbances. They have shown clearly that the structure, composition and dynamics of the ionosphere and thermosphere are altered in or near the auroral zone during these periods. The auroral zone is known to expand away from the geomagnetic poles with the increasing geomagnetic and magnetospheric activity levels. Also, the regions of strong magnetospheric electric fields mapped into the polar ionosphere undergo a similar equatorward expansion. The direct heating effects of precipitating ions and electrons are however, limited to mainly the dayside cusp. These energetic electrons and ions enhance the plasma density by ionising the neutral atoms and molecules in the thermosphere.

During geomagnetic storms, the convection electric field drives the enhanced ionospheric plasma of the auroral oval and around the polar cap to high velocities (E×B drift, ~E representing the convection electric field and ~B the magnetic field intensity). The moving ions impart significant amount of momentum to neutrals via 'ion-drag'. At the same time, the resistance offered by the neutral atoms and molecules causes the dissipation in Pederson current component through increased Joule heating. Outside the oval and over the polar cap regions the electrodynamic heating is effective depending upon the electrical conductivity in that area. The electrodynamical heating is known to peak at about ~ 130 km. The maximum particle heating occurs at an altitude of ~110 km. The lower ionospheric region, around ~150 km, over high latitudes responds directly to the 'auroral input'. Large scale advection and convection forced upon the thermosphere by geomagnetic heating causes the high latitude F-region neutral gas composition to change dramatically, as a part of the thermospheric response to Joule and particle heating. The varying composition structure with altitude during geomagnetic disturbances is the consequence of the convection of these horizontal winds with the mean vertical wind flow, as a part of global wind system.

Significant enhancement of molecular nitrogen (N_2) density, and a corresponding decrease of atomic oxygen density are seen in the high latitudes during intense storms. Enhanced molecular concentrations cause significant depletions in F-region plasma density by greatly increasing the effective recombination rates, while the ionisation rates are only slightly modified by auroral precipitation. However, atomic oxygen (*O*) the dominant thermospheric species, usually registers a depletion below 300 km and a slight increase above. The E-region wind velocities are typically lower than that of the F-region, and the basic wind pattern follows the ion convection over high latitudes. Further, the temporal variabilities in the energy injection at high latitudes trigger a broad spectrum of atmospheric waves, namely Traveling Atmospheric Disturbances (TADs). As a part of global-scale disturbances, the low latitude, thermosphere - ionosphere system follows the initial high latitude geomagnetic forcing; and it is known to show distinctive storm time features in composition, dynamics and energetics [figure 5].

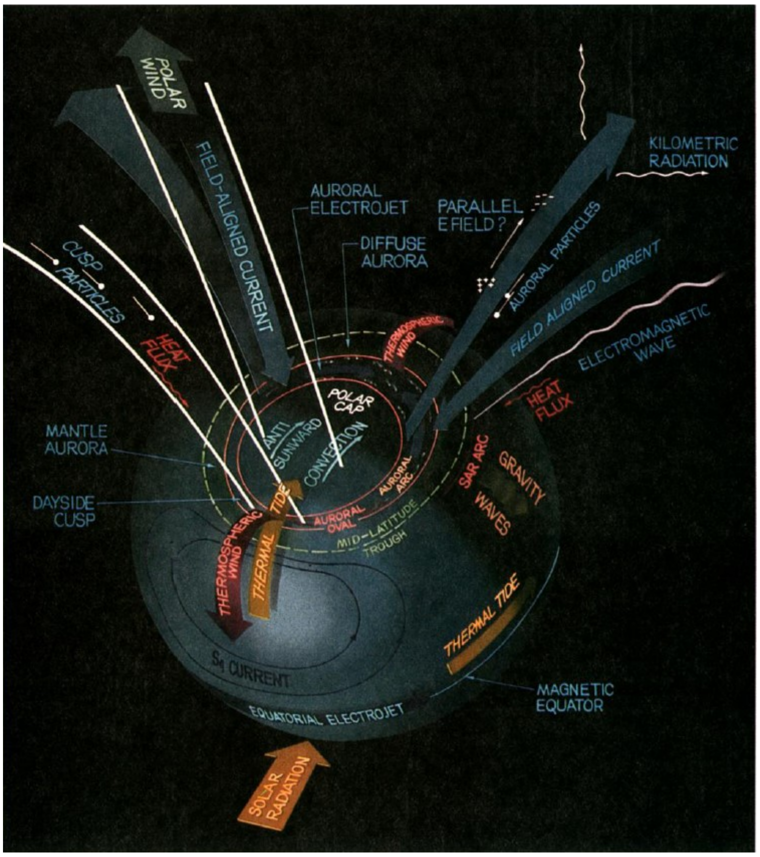

Figure 5: Illustration of many of the phenomena associated with magnetosphere-ionosphere-atmosphere coupling (*R. A. Hoffman 1988*)

Geomagnetic Storms-The Low Latitude Thermosphere Ionosphere during Geomagnetic Storms

One of the least explored aspect is the behaviour of low and equatorial latitude Thermosphere-Ionosphere System during geomagnetic storm. It is yet to be comprehended in totality how the large amount of energy that gets dumped into high latitude regions during storms gets redistributed to low latitudes. The magnetosphere - ionosphere - thermosphere coupling is believed to be the only route through which the magnetospheric disturbances get propagated to low latitudes. Three main processes which play important roles in the redistribution of storm energy and momentum to low latitudes are (i) large scale meridional wind circulation; (ii) gravity wave or TADs; and (iii) Ring current. The thermospheric composition and temperature are essentially controlled by vertical and horizontal advection and molecular diffusion. Due to the large energy input during the geomagnetic storms over high latitude regions, the atmosphere gets heated up that causes the air to move upward and outwards i.e., away from the source region. In its upward expansion, the air undergoes adiabatic cooling but the air is, nevertheless, hotter than the normal (even during geomagnetically quiet periods) as it flows equatorwards.

As a result of the pressure gradients between the equatorward/low and high latitude regions, a strong meridional circulation gets established, which produces some heating because of the relative motion between ions and neutrals i.e. ion-neutral collisions. On the descending part of the meridional circulation over low latitudes the air undergoes adiabatic compression which heats the air further. The wind flow and the pressure differences constantly modify each other, as the flow is continuous spatially. Existence of such circulations during storms, has indeed been observed and confirmed by the presence of strong winds over mid latitudes. However, there have been relatively few direct observations on the thermospheric dynamics at low and equatorial latitudes.

In an important observation it has been seen that at times during storms, because of the hemispheric asymmetry and the shape of energy input function with time, poleward winds also can get setup over low latitudes. All these meridional wind circulations would affect the composition, dynamics and energetics. The model estimated and actually observed time lag between the setting up of the meridional circulation cell from the time of intense high latitude heating during a storm, is around 8-10 hrs. The temporal variations of energy injection at high latitudes during disturbed periods generally triggers a broad spectrum of waves which may combine to form a Traveling Atmospheric Disturbances (TAD) or gravity waves. These TADs are pulse like superposition of atmospheric waves. TADs move away from the source regions i.e. high latitudes, towards middle and lower latitudes and dissipate their energy through molecular viscosity, thereby transporting energy. At low latitudes, the energy dissipation of the two TADs launched in both the hemispheres cause an increase of the temperature and densities. One essential feature of TADs is that they are associated with an equatorward meridional wind of moderate magnitude. It is this transient increase of meridional wind velocity which is believed to be responsible for the generation of positive ionospheric storms at middle latitudes. TADs, also continuously lose energy by heat conduction and ion drag, and they may cause compressional heating too. It is this energy dissipation which appears as geomagnetic activity effect at low latitudes. These TAD effects can be seen even after a prolonged time i.e. 24-30 hrs. and as early as 10hrs. after the main energy dissipation [Figure 6].

An additional energy source that is active during storm time is the ring current formed in the magnetosphere. During geomagnetic storms, large amount of energy is contained in ring current in the form of trapped particles. This trapped energy is released directly into the thermosphere by means of neutral particle precipitation, produced due to resonant charge exchange process and also by field aligned charged particle precipitation over high latitudes. At middle and lower latitudes some of these trapped ring current ions are dumped directly into the thermosphere if their mirror height is lowered to the thermosphere sufficiently fast. There is also a more continuous flux of energetic neutrals showering from higher altitudes in all directions due to the charge exchange with the exospheric constituents over a much greater range of mirror heights. The heating effect at middle latitudes and ionospheric perturbations at low and middle latitudes due to these currents have been dealt with in the literature. The first ever Energetic Neutral Atom (ENA) image of earth's ring current was reported by *Roelef et al.* (1987), using ISEE-1 energetic particle data. Recently *Lui et al.* [1996] reported ENA detection by energetic particles and ion composition (EPIC) instrument onboard Geotail spacecraft during a magnetic storm on Oct. 29-30, 1994. The ENA fluxes and the rate of recovery of *Dst* were found to be consistent with charge exchange, implying that ENA precipitation is a significant energy loss process for storm time ring current.

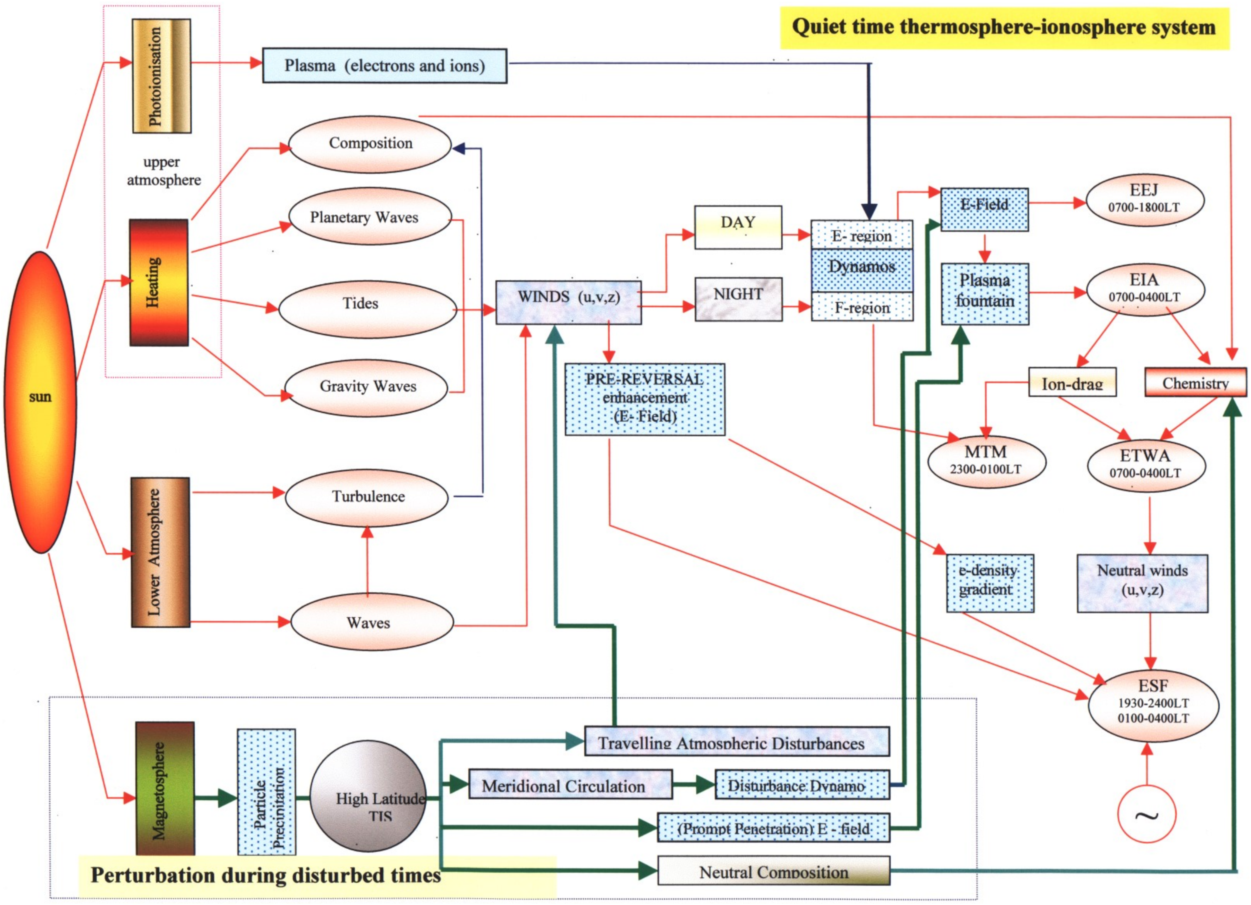

Figure 6: Processes affecting thermosphere-ionosphere system during Quiet and Disturbed times *(Sastri, Sridharan and Pant, 2003)*

Space Situational Awareness

Today there are a whole lot of technological and social infrastructures that are directly/indirectly affected by the space weather. Among these, the most vulnerable are satellite missions, navigation and communication, electric power grids and pipeline operations on ground, space faring astronauts, airline communication, mining and many others.

For instance, during active space weather conditions the satellites in orbit face two major dangers, namely (a) Solar flares can damage the electronics inside the panels/satellite, (b) damage to solar panels in space besides regular wear-and tear. Since, solar panels are large and fragile constructions that always need to be pointed at the Sun. During flares or CMEs, the sudden enhancement in particle and radiation fluxes can adversely affect the panels. In context of the latter, micrometeorites, which are tiny, gravel-sized bits of rock and other space junk floating in space can scratch or crack solar panels upon impact. In addition to this, there are a few other potential threats that can affect man made infrastructures in space.

Electron Damage to Satellites

During an explosive Solar Particle Event (SPE) satellites could suffer damage. These events are usually associated with solar flares and coronal mass ejections. Protons and electrons are emitted at high velocities which can cause problems in orbiting satellites. A long duration of high energy electron fluxes that occur during times of high speed solar wind streams can also cause such problems. Interestingly, these high speed streams are more likely to occur during times of sunspot minimum. High energy electrons penetrate the spacecraft's outer surface; they penetrate the dielectric materials such as circuit boards and the insulation in coaxial cables. This gives rise to intense electric fields; as soon as they exceed the breakdown potential of the material they produce sudden discharges (similar to a stroke). This discharge damages the system: components may start to burn, semiconductors may be destroyed. Damaging conditions are assumed when the daily electron flux (which is given by the number of high energy electrons per sterad per day meets either of the following conditions: greater than 3×10^8 per day for 3 consecutive days; or greater than 10^9 for a single day.

Single-event upsets (SEUs) are random errors in semiconductor memory that occur at a much higher rate in space than on the ground. They are non-destructive, but can cause a loss of data if left uncorrected. Energetic charged particles pass through sensitive regions of a chip. Depending on their energy and angle of impact, individual particles can cause a large current impulse sufficient to change the state of a bistable circuit element. Modern microelectronic devices can suffer from single event effects caused by cosmic radiation neutrons in the atmosphere. The phenomenon has been observed both on ground and at aircraft altitudes. The neutron flux at aircraft altitudes (<15 km) is large enough to make the neutron single event effects a problem to aircraft electronics. The most studied device type is static random access memories (SRAM) since those devices have a very high density of transistors, making them sensitive to particle radiation.

Atmospheric Drag

Satellites in low Earth orbit, with perigee altitudes below 2000 km, are subject to atmospheric drag. This force very slowly circularizes the orbits and the altitude is reduced too. The rate of decay of these orbits becomes extremely rapid at altitudes less than 200 km. As soon as the satellite is down to 180 km it will only have a few hours to live and after several revolutions around the Earth it will re-entry down to Earth. At that phase the temperature is very high and most of the satellite will vaporize. Only large satellites become not fully vaporized and component pieces of them may reach the ground. The essential parameter for this deceleration is the air density. This varies along the satellite's orbit and is a function of latitude, longitude, time of day, season etc. At a fixed point in space the density can be expressed in terms of the two space environmental parameters: 10.7 cm solar radio flux (F10.7), geomagnetic index It is extremely difficult to predict exactly when a satellite will re-enter the atmosphere. The reason for that is that the space environment is not exactly predictable and there are also unresolved variations in atmospheric density. The accuracy of the prediction is in the order of 10 %.

Communication and Navigation Errors

Many of our present day applications, such as navigation and communication, require exact latitude, longitude and altitude information in real time. However both navigational systems, space-systems as well as systems on the surface suffer significant losses during transmission through the ionosphere. For instance, the GPS operations are affected by the total electron content of the ionosphere along the path to the satellite and are thus influenced by geomagnetic storms. Though solar X-rays impact only the sunlit hemisphere of Earth, the geomagnetic storms are ubiquitous across the globe. The ionospheric response to the storms also depends on the latitude. The conditions nearer to the dip equator or nearer to the poles vary for the user. It must also be stressed that a quiet undisturbed geomagnetic field does not necessarily dictate an undisturbed equatorial ionosphere. Unpredictable density enhancements can occur in the evening hours and cause scintillations which affect both dual- and single-frequency GPS receivers. The ionosphere affects the propagation of radio signals in different ways depending on their frequencies. The influence of solar and geomagnetic activity (driven by solar events) on various systems can be given as follows.

The HF Communications undergo increased absorption, fading and flutter. At the same time, the Maximum Usable Frequency (MUF) for HF communication decreases while Lowest Usable Frequency (LUF) gets enhanced. The radar energy gets scattered more and the error in Range, Elevation and Azimuth also enhances. Very strong radio scintillations are seen for ionosphere affecting loss of lock and dip in SNR for radio systems. The most important of all, significant errors creep into the position estimation by the Navigation systems.

Geomagnetically Induced Currents

Ground effects of space weather are generally known as GIC (geomagnetically induced currents). These currents are driven by the geoelectric field associated with a magnetic disturbance in electric power transmission grids, communication cables and railway equipment. GIC are dc currents. They may cause several effects because they increase existing current and this may cause saturation. Increase of harmonics, unnecessary relay trippings, increase in reactive power loss, voltage drops, permanent damage to transformers, black out of the whole system are some of the dire consequences of space weather induced enhancements in GIC. When flowing from the pipeline into the soil, GIC may increase corrosion of the pipeline, and the voltages associated with GIC disturb the cathodic protection system and standard control surveys of the pipeline. On March 13, 1989, the most famous GIC failure occurred in the Canadian Hydro-Quebec system during a great magnetic storm on March 13, 1989. The system suffered from a nine-hour black-out.

Geomagnetic Indices

Studies have shown that the extent of the depression in geomagnetic field strength is a useful proxy for the level of space weather induced geomagnetic disturbance. One important aspect of the 'indices' is that if the index series is homogeneous in time representing the phenomena well, then it could be used as a tool for statistical studies concerning its time variation, and its relationship with other phenomena. The fundamental problem in defining a geomagnetic index is the separation of geomagnetic variations observed at any given time, at any place, caused by permanent sources of field, from those which are not permanent. These irregular or non permanent variations were classified into two sets. The present indices recognised by IAGA (International Association of Geomagnetism and Aeronomy), also constitute two distinct families of indices. The most frequently used indices are *Kp* and *ap* (the planetary indices) and; *Dst*, a non-planetary index for equatorial ring current). The *Kp* index, determined to an accuracy of 1/3 of a unit, is obtained by combining index K, which runs from 0 to 9 related to the amplitude of field variation by a quasi logarithmic scale, from twelve observatories around the world. Typically the qualification K = 9 is a geomagnetic disturbance of 300 nT for low latitude, 500 nT for mid latitudes and 2000 nT for stations in the auroral zones. And for index *ap*, the field variations of each magnetic field components i.e. horizontal H, vertical Z and dip (D) recorded every three hour at any station are considered. The greatest of the three deviations is called the amplitude (a). The amplitude 'a' for twelve observatories are combined and averaged, after removing the solar quiet day (Sq) and lunar (L) variations, to define the index *ap*. These indices especially *ap* is used as an input to the modern day thermospheric - ionospheric models for representing different geophysical conditions. On the other hand, the '*Dst*' is purely a ring current index obtained from low latitudes, sufficiently away from the equatorial electrojet current region. Notwithstanding the fact that all the sources and variations involved in the observed field fluctuations of *Dst*, are not fully understood, *Dst* is the only index which describes the event with maximum accuracy.

As we have seen the fast and effective communication of space weather effects to the public is very important. For that reason the US NOAA (National Oceanic and Atmospheric Administration) has introduced the space weather scales. The NOAA space weather scales have been grouped into three different parts as (a) Geomagnetic storms, (b) Solar radiation storms, and (c) Radio blackouts.

Space Weather Prediction

On account of the concerted observational efforts in India in the past, following four aspects of the solar – terrestrial interactions have emerged to be of primary importance in this context. First, the probing of the magnetic field structures on the sun and solar wind disturbances. Second, the investigation of Solar and interplanetary origin of geomagnetic disturbances. Third, the day-to-day variability of terrestrial magnetosphere-ionosphere-atmosphere system. Fourth, understanding the effect of these disturbances on space based technological systems and manifestations thereof.

To help make significant progress in addressing the above mentioned four aspects of space weather, the research community in India is being actively supported by technologies developed through its space program. Observations of Scintillations for trans-ionospheric communication and navigation over the low and equatorial locations in India are used to provide warning on potential degradation of conditions owing to impending space weather. Networking of all the space weather measurements in the country is being strengthened, with an idea of ultimately having an Indian network for Space Weather impact monitoring. Networking of all the space weather measurements in the country is being strengthened, with an idea of ultimately having an operational, possibly real time, Indian network for Space Weather impact monitoring. With these ground based observatories across India and experiments in space like the ASTROSAT (in orbit) & Aditya-L1 (to be launched soon), ISRO in particular and India in general, is well poised to contribute to the global effort in the direction of Space weather research/forecast in a big way in coming years.

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