Chapter One

THE SUN

(1-1) Introduction

In this chapter we introduced the properties of stars and the properties of the sun as a typical star; then we talked about the structure of the sun which is including the core, Radiative zone, convection zone and the magnetic field.

(1-2) The Sun a Typical Star

Our Sun is the only star which is close enough to observe details on its surface such as sunspots, faculae, prominences, coronal holes, flares, …etc., which are all summarized as solar activity phenomena. Therefore, the study of the Sun is important for astrophysics in general. Theories about stellar structure and evolution can be studied in detail on the Sun.

On the other hand, the Sun is the driving factor for the climate on the Earth and the structure and shape of the Earth's magnetosphere thus determining and influencing the near Earth space environment. Therefore, the study of solar terrestrial relations is of great importance for our modern telecommunication systems both based on Earth and in space.

The Sun is the nearest star to us and our solar system is located in the Milky Way Galaxy. Our galaxy contains more than 2×10^{11} solar masses (i.e. at least as many stars). The mass of the galaxy can be inferred from the rotation of the system. All stars rotate about the center of the galaxy which is at a distance of about 27 000 light years (Ly) to us.

At the location of the Sun in the galaxy, one period of revolution about the galactic center is about 200 Million years. Galaxies in general contain some 1011 stars. About 50% of the stars have one or more stellar companions. Up to now more than 150 planetary companions were detected around nearby stars, so called extra solar planets. [1]

(1-3) Properties of Stars

The only information we can directly obtain from a star is its radiation and position. In order to understand the physics of stellar structure, stellar birth and evolution we have to derive quantities such as stellar radii, stellar masses, composition, rotation, magnetic fields etc. We will just very briefly discuss how these parameters can be derived for stars:

Stellar distances: a fundamental but not an intrinsic parameter. Stellar distances can be measured by determining their parallax that is the angle the Earth's orbit would have seen from a star. This defines the astrophysical distance unit parsec. A star is at a distance of 1 parsec if the parallax is. 1 pc = 3.26 Ly.

Stellar radii: once the apparent diameter of a star is known than its real diameter follows from its distance d. The problem is to measure apparent stellar diameters since they are extremely small. One method is to use interferometers; one other method is to use occultation of stars by the moon or mutual occultation of stars in eclipsing binary systems. All these methods are described in ordinary textbooks about astronomy.

Stellar masses: can be determined by using Kepler's third law in the case we observe a binary system. Stellar masses are very critical for stellar evolution, however we know accurate masses only for some 100 stars.

Once mass and radius are known, the density and the gravitational acceleration follow. These parameters are important for the stellar structure.

Stellar magnetic fields: as it will be discussed in more detail when we Talking about sunspots [1]

(1-4) The Sun Basic Properties

As it has been mentioned, the Sun is a G2V star in the disk of our Galaxy. The mass of the Sun is:

$$M = 1.99 \times 10^{30}\ \text{kg} \quad (1\text{-}1)$$

An application of Kepler's third law gives us the mass of the Sun if its distance is known which again can be derived from Kepler's third law:

$$a^3/P^2 = G/4\pi 2\ (M1 + M2) \qquad (1\text{-}2)$$

In our case (a) denotes the distance Earth-Sun (150×10^6 km), P he revolution period of the Earth around the Sun (1 year), M1 the mass of the Earth and M2 the mass of the Sun. One can make the assumption that $M1 << M2$ and therefore $M1+M2 \sim M2$.

If we know the distance of the Sun and its angular diameter the solar radius is obtained:

$$r = 6.96 \times 10^8 \text{ m}$$

The measurement of the Sun's angular diameter is not trivial; one possibility is to define the angular distance between the inflection points of the intensity profiles at two opposite limbs. Such profiles can be obtained photo electrically and the apparent semi diameter at mean solar distance is about 960 seconds of arc (").

The orbit of the Earth is elliptical and at present, perihelion (smallest distance of the Sun) is in January. Knowing the mass and radius of the Sun, the mean density can be calculated:

$$\bar{\rho} = 1.4\text{g/cm3} \qquad (1\text{-}3)$$

The gravitational acceleration is given by:

$$g = GM/R^2 = 274\text{m/s2} \qquad (1\text{-}4)$$

The solar constant is the energy crossing unit area of the Earth's surface perpendicular to the direction from the Earth to the Sun in every second. In SI the units are Wm−2. UV and IR radiation from the Sun is strongly absorbed by the Earth's atmosphere. Therefore, accurate measurements of the solar constant have to be done with satellites. ACRIM on SMM and ERB on Nimbus 7 showed clearly that the presence of several large sunspots which are cooler than their surroundings depress the solar luminosity by ∼ 0.1%. The Variability IRradiance Gravity Oscillation (VIRGO) experiment on the SOHO satellite is observing total solar and spectral irradiances at 402 nm (blue channel), 500 nm (green channel), and 862 nm (red channel) since January 1996 the solar luminosity is [1]:

$$L\_ = 3.83 \times 10^{26}\text{W}$$

And the effective temperature:

$$Teff\_ = 5780\text{K}$$

(1-5) **Structure of the Sun**

Astrophysicists classify the Sun as a star of average size, temperature, and brightness—a typical dwarf star just past middle age. It has a power output of about 1026 watts and is expected to continue producing energy at that rate for another 5 billion years. The Sun is said to have a diameter of 1.4 million kilometers, about 109 times the diameter of Earth, but this is a slightly misleading statement because the Sun has no true "surface." There is nothing hard, or definite, about the solar disk that we see; in fact, the matter that makes up the apparent surface is so rarified that we would consider it to be a vacuum here on Earth. It is more accurate to think of the Sun's boundary as extending far out into the solar system, well beyond Earth. In studying the structure of the Sun, solar physicists divide it into four domains: the interior, the surface atmospheres, the inner corona, and the outer corona. [1]

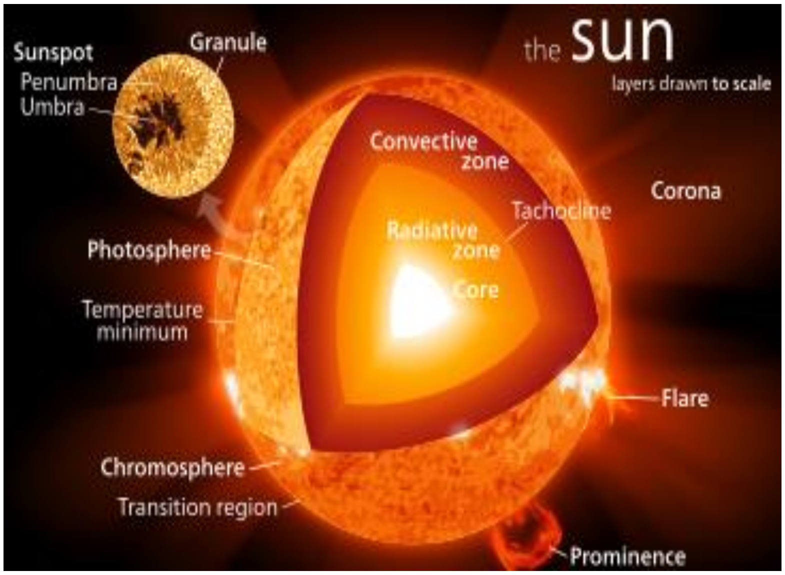


Figure (1-1)

(1-5-1) The Core

The core of the Sun is considered to extend from the center to about 20–25% of the solar radius.¨ It has a density of up to 150 g/cm^3 (about 150 times the density of water) and a temperature of close to 15.7 million kelvins (K). By contrast, the Sun's surface temperature is approximately 5,800 K. Recent analysis of SOHO “Solar and Hemispheric Observatory “mission data favors a faster rotation rate in the core than in the rest of the Radiative zone. Through most of the Sun's life, energy is produced by nuclear fusion through a series of steps called the p–p (proton–proton) chain; this process converts hydrogen into helium. Only 0.8% of the energy generated in the Sun comes from the CNO”carbon–nitrogen–oxygen” cycle. [2]

The core is the only region in the Sun that produces an appreciable amount of thermal energy through fusion; 99% of the power is generated within 24% of the Sun's radius, and by 30% of the radius, fusion has stopped nearly entirely. The rest of the star is heated by energy that is transferred outward by radiation from the core to the convective layers just outside. The energy produced by fusion in the core must then travel through many successive layers to the solar photosphere before it escapes into space as sunlight or the kinetic energy of particles. [3]

(1-5-2) **Radiative zone**

Below about 0.7 solar radii, solar material is hot and dense enough that thermal radiation is the primary means of energy transfer from the core. This zone is not regulated by thermal convection; however the temperature drops from approximately 7 to 2 million kelvin with increasing distance from the core. This temperature gradient is less than the value of the adiabatic lapse rate and hence cannot drive convection [4]. Energy is transferred by radiation—ions of hydrogen and helium emit photons, which travel only a brief distance before being reabsorbed by other ions. The density drops a hundredfold (from 20 g/cm3 to only 0.2 g/cm3) from 0.25 solar radii to the top of the Radiative zone.

The Radiative zone and the convective zone are separated by a transition layer, the tachocline. This is a region where the sharp regime change between the uniform rotation of the Radiative zone and the differential rotation of the convection zone results in a large shear—a condition where successive horizontal layers slide past one another. The fluid motions found in the convection zone above, slowly disappear from the top of this layer to its bottom, matching the calm characteristics of the Radiative zone on the bottom. Presently, it is hypothesized that a magnetic dynamo within this layer generates the Sun's magnetic field. [5]

(1-5-3) Convective zone

In the Sun's outer layer, from its surface to approximately 200,000 km below (70% of the solar radius away from the center), the temperature is lower than in the radiative zone and heavier atoms are not fully ionized. As a result, radiative heat transport is less effective. The density of the gases is low enough to allow convective currents to develop. Material heated at the tachocline picks up heat and expands, thereby reducing its density and allowing it to rise. As a result, thermal convection develops as thermal cells carry the majority of the heat outward to the Sun's photosphere. Once the material cools off at the photosphere, its density increases, and it sinks to the base of the convection zone, where it picks up more heat from the top of the Radiative zone and the cycle continues. At the photosphere, the temperature has dropped to 5,700 K and the density to only 0.2 g/m3 (about 1/6,000th the density of air at sea level).

The thermal columns in the convection zone form an imprint on the surface of the Sun as the solar granulation and super-granulation. The turbulent convection of this outer part of the solar interior causes “small-scale” dynamos that produce magnetic north and south poles all over the surface of the Sun. The Sun's thermal columns are Bénard cells and take the shape of hexagonal prisms. [5]

(1-5-4) Photosphere

The visible surface of the Sun, the photosphere, is the layer below which the Sun becomes opaque to visible light. Above the photosphere visible sunlight is free to propagate into space, and its energy escapes the Sun entirely. The change in opacity is due to the decreasing amount of H^- ions, which absorb visible light easily. Conversely, the visible light we see is produced as electrons react with hydrogen atoms to produce H^- ions. The photosphere is tens to hundreds of kilometers thick, being slightly less opaque than air on Earth. Because the upper part of the photosphere is cooler than the lower part, an image of the Sun appears brighter in the center than on the edge or limb of the solar disk, in a phenomenon known as limb darkening. The spectrum of sunlight has approximately the spectrum of a black-body radiating at about 6,000 K, interspersed with atomic absorption lines from the tenuous layers above the photosphere. The photosphere has a particle density of ~1023 m−3 (about 0.37% of the particle number per volume of the Earth's atmosphere at sea level). The photosphere is not fully ionized—the extent of ionization is about 3%, leaving almost all of the hydrogen in atomic form. [6]

(1-5-5) Atmosphere

The parts of the Sun above the photosphere are referred to collectively as the solar atmosphere. They can be viewed with telescopes operating across the electromagnetic spectrum, from radio through visible light to gamma rays, and comprise five principal zones: the temperature minimum, the chromosphere, the transition region, the corona, and the heliosphere. The coolest layer of the Sun is a temperature minimum region about 500 km above the photosphere, with a temperature of about 4100 K. This part of the Sun is cool enough to allow the existence of simple molecules such as carbon monoxide and water, which can be detected via their absorption spectra.

The chromosphere, transition region, and corona are much hotter than the surface of the Sun. The reason has not been conclusively proven; evidence suggests that Alfven waves may have enough energy to heat the corona.

Above the temperature minimum layer is a layer about 2000 km thick, dominated by a spectrum of emission and absorption lines. It is called the chromosphere from the Greek root chroma, meaning color, because the chromosphere is visible as a colored flash at the beginning and end of total solar eclipses. The temperature in the chromosphere increases gradually with altitude,

Ranging up to around 20000 K near the top. In the upper part of the chromosphere helium becomes partially ionized. [7]

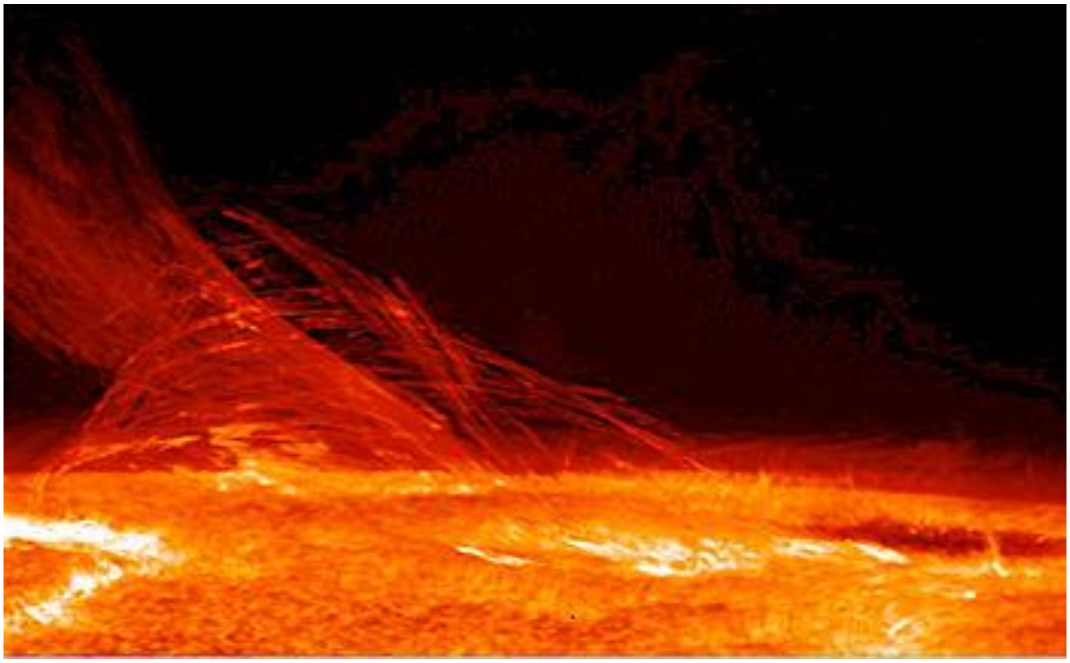


Figure (1-2) : Taken by Hinode's Solar Optical Telescope on January 12, 2007, this image of the Sun reveals the filamentary nature of the plasma connecting regions of different magnetic polarity.

Above the chromosphere, in a thin (about 200 km) transition region, the temperature rises rapidly from around 20,000 K in the upper chromosphere to coronal temperatures closer to 1,000,000 K. The temperature increase is facilitated by the full ionization of helium in the transition region, which significantly reduces radiative cooling of the plasma. The transition region does not occur at a well-defined altitude. Rather, it forms a kind of nimbus around chromospheric features such as spicules and filaments, and is in constant, chaotic motion. The transition region is not easily visible from Earth's surface, but is readily observable from space by instruments sensitive to the extreme ultraviolet portion of the spectrum.

The corona is the next layer of the Sun. The low corona, near the surface of the Sun, has a particle density around 1015–1016 m−3. The average temperature of the corona and solar wind is about 1,000,000–2,000,000 K; however, in the hottest regions it is 8,000,000–20,000,000 K While no complete theory yet exists to account for the temperature of the corona, at least some of its heat is known to be from magnetic reconnection. The corona is the extended atmosphere of the Sun, which has volume much larger than the volume enclosed by the Sun's photosphere. Waves at the outer surface of the corona which randomly blow to even further distance from the Sun is called the solar wind, and is one of the Sun's influence to the whole Solar System.

The heliosphere, the tenuous outermost atmosphere of the Sun, is filled with the solar wind plasma. This outermost layer of the Sun is defined to begin at the distance where the flow of the solar wind becomes superalfvénic—that is, where the flow becomes faster than the speed of Alfven waves, at approximately 20 solar radii (0.1 AU). Turbulence and dynamic forces in the heliosphere cannot affect the shape of the solar corona within, because the information can only travel at the speed of Alfven waves. The solar wind travels outward continuously through the heliosphere, forming the solar magnetic field into a spiral shape, until it impacts the heliopause more than 50 AU from the Sun. In December 2004, the Voyager 1 probe passed through a shock front that is thought to be part of the heliopause. Both of the Voyager probes have recorded higher levels of energetic particles as they approach the boundary. [6]

(1-5-6) **Magnetic field**

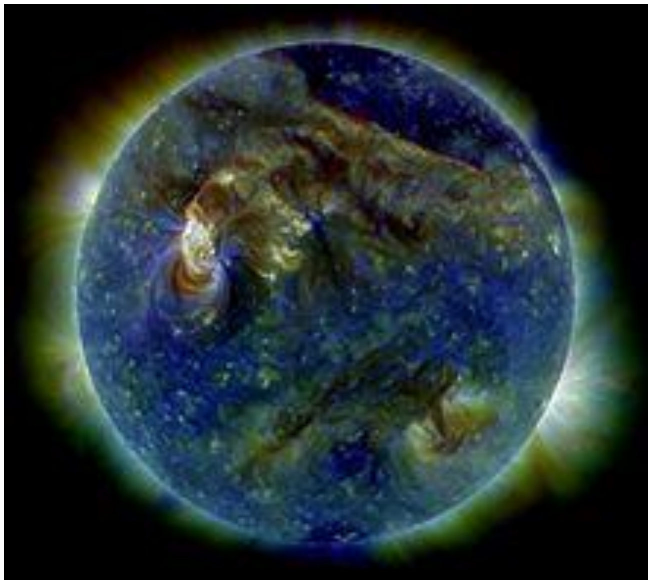


Figure (1-3) In this false-color ultraviolet image, the Sun shows a C3-class solar flare (white area on upper left), a solar tsunami (wave-like structure, upper right) and multiple filaments of plasma following a magnetic field, rising from the stellar surface.

Figure (1-4): The Heliospheric current sheet extends to the outer reaches of the Solar System, and results from the influence of the Sun's rotating magnetic field on the plasma in the interplanetary medium.

The Sun is a magnetically active star. It supports a strong, changing magnetic field that varies year-to-year and reverses direction about every eleven years around solar maximum. The Sun's magnetic field leads to many effects that are collectively called solar activity, including sunspots on the surface of the Sun, solar flares, and variations in solar wind that carry material through the Solar System. The effects of solar activity on Earth include auroras at moderate to high latitudes and the disruption of radio communications and electric power. Solar activity is thought to have played a large role in the formation and evolution of the Solar System. Solar activity changes the structure of Earth's outer atmosphere. [8]

Chapter Two

SUNSPOTS

(2-1) Introduction

In this chapter we introduced the discovery of the sunspot and the physic of the sunspot which it's consist of a dark regions (umbra) then we introduced the relation between sunspot and magnetic field then we introduced a solar cycle prediction, the relation between sunspot and the solar cycle and the wolf number R(number of sunspots).

(2-2) Discovery of Sunspots

When the Sun is very low just above the horizon one can make a short glimpse on it with the unprotected naked eye. Chinese astronomers were the first who reported on dark spots visible on the Sun. In the year 1611 sunspots were observed for the first time through a telescope by four men: J. Goldsmith (Holland), G. Galilei (Italy), Ch. Scheiner (Germany) and Th. Herriot (England). The first publication on that topic appeared from Goldsmith (he is better known by his Latin name Fabricius). He even argued that the Sun must rotate since the sunspots move across the disk. Since he was a Jesuit he first suspected some defect in his lescope when he observed the spots. Then he failed to persuade his ecclesiastical superiors who refused to allow him to publish his discovery. However, Scheiner announced his discovery in three anonymous letters to a friend of Galileo and Galileo responded in three letters in 1612 (the sunspot letters) that he had discovered the sunspots. Of course Scheiner and Galileo became enemies. Scheiner later reported his discoveries in his work Rosa Ursine sive Sol in 1630. Both scientists noted that the spots appear only within zones of low latitudes at either side of the equator. There are never spots near the poles. [1]

After the initial interest and the publication of Scheiner's major work the interest in sunspots vanished. In 1977 Eddy showed that this must be seen in connection with the fact that during 1640-1705 there was a great reduction in the number of sunspots seen on the Sun which is now known as the Maunder Minimum.

The next significant discovery was made by Schwab who was a German apothecary and bought a telescope in 1826 in order to search for a planet inside the orbit of Mercury. He recorded the occurrence of sunspots over 43 years and reported on aperiodicity of their occurrence of about 10 years. In 1851 appeared his publication on the 11 year periodicity of the annually averaged sunspot numbers. Several years later Carrington showed from his observations that the Sun rotates differentially; a point at the equator rotates more rapidly than one at higher latitudes. He defined an arbitrary reference point on latitude 100 as longitude zero and a rotation completed by this point is known as Carrington rotation (CR) [3]. The sidereal Carrington rotation is 25.38 days, the synodic value varies a value is 27.2753 days).

Carrington was also the first to see a white light flare on the Sun in the morning of Sep. 1, 1859, during sketching sunspot rejections with a friend. Suddenly two crescent-shaped patches broke out, brightened, moved a distance twice their length, and then faded away as two dots within five minutes. Carrington reported to the Royal Astronomical Society that at 4 hours after midnight the magnetic instruments indicated a great magnetic storm. So he was in fact the first who noticed that there exists a connection between solar phenomena and disturbances on Earth.

R. Wolf (1816-1893) studied all available records and derived a more accurate estimate for the sunspot cycle. In 1848 he introduced the relative (Zurich) sunspot number RZ as a measure for solar activity. Sunspot often appears as groups. If g denotes the number of sunspot groups and f the number of individual spots, then

$$R_z = k\,(10g + f) \qquad (2\text{-}1)$$

K... personal reduction factor. Today more than 30 observatories contribute to determine this value [1]

(2-3) the Physics of Sunspots

Sunspots consist of dark central regions, called umbra and a surrounding less dark filamentary region called penumbra. The umbra diameter is about 10 000 km but for the largest spots may exceed 20 000 km. Penumbral diameters are in the range of 10 000 -15 000 km. Sunspots evolve and some of them are visible over more than 1 rotation period. The observations of sunspots showed that the rotation of the Sun is not like that of a solid body.

Another interesting phenomenon is the Wilson depression. In 1769 Wilson observed a very large spot nearing the west limb and noted that the penumbra on the further side from the limb gradually contracted and finally disappeared. When the spot reappeared at the east limb some two weeks later, the same behavior was displayed by the penumbra on the opposite site of the spot. The surface of a sunspot is depressed below the surface of the surrounding plasma.

The temperature of the umbra is about 4 000 K whereas the temperature of the solar surface is about 6 000 K. According to Stefan's law the total energy emitted per unit area by a black body at temperature T is proportional to T^4; the above mentioned temperature difference between umbra and photosphere means that the energy flux through a given area of the umbra is $\sim$ 20% of that through an equivalent area of the photosphere. The penumbra has a temperature between umbra and solar surface. In the penumbra we observe also a radial outflow of matter with the velocity increasing outwards with a characteristic speed of 1 to 2 kms/s (Evershed effect).

In 1908 Hale discovered that the spectral lines are split in the sunspots. This is caused by the Zeeman Effect in the presence of strong magnetic fields. In the absence of magnetic fields several quantum mechanical state may possess the same energy but the magnetic fields destroy this symmetry resulting in a splitting of the energy levels. The displacement of the lines due to the Zeeman Effect is given by:

$$\Delta\lambda = 4.7 \times 10^{-8} g\lambda^2 B$$

The wavelength λ is given in nm, the Land´efactor $g*$ depends on the spin and orbital momentum of the levels and B denotes the magnetic induction given in Tesla.

$$1\text{Tesla} = 104\text{Gauss} = \text{Vs/m}^2$$

The strength of the magnetic field is in the order of 3 000 Gauss.

Small dark spots with diameters < 2 500km lacking penumbrae are called pores. They exist within groups or appear also as isolated structures. Their lifetimes are in the range of a few hours to several days.

Sunspot groups tend to emerge either sequentially at the same or similar Carrington longitudes, which are designated as active longitudes, or to overlap in clusters. The distribution of sunspots is non-axisymmetric and spot group formation implies the existence of two persistent active longitudes separated by 180[1]

(2-4) Sunspots and Magnetic Fields

Observations demonstrated that spots often occur in bipolar magnetic groups. The magnetic polarity of the leading spot in the pairs changes from one 11 year cycle to the next- this is known as Hale’s law. There is a22 year magnetic cycle. Spots appear as a magnetic flux tube rises and intersects with the photosphere. The magnitude of the magnetic induction is 0.3 T in the umbra and 0.15 T in the penumbra. In the umbra the field is approximately vertical, and the inclination increases through the penumbra.

Hales observations also suggested that the Sun has an overall dipolar magnetic field (10^{-4} T). This very weak dipolar field is reversed over the magnetic cycle. Almost all of the photospheric field outside sunspots is concentrated in small magnetic elements with a magnetic induction between 0.1 and 0.15 T.

Only the surface properties of the flux tube that defines a spot can be observed.

The question is, how the field structure changes with depth. The simplest model is a monolithic column of flux. Let us assume that the pressure inside the flux tube is negligible compared to the magnetic pressure. We also assume that the gravitational force is unimportant in obtaining an approximate idea of the magnetic field structure; the magnetic field in cylindrical polar coordinates can be taken to be current free [1]

(2-5) Solar Cycle Prediction

Among the most reliable techniques are those that use the measurements of changes in the Earth's magnetic field at, and before, sunspot minimum. These changes in the Earth's magnetic field are known to be caused by solar storms but the precise Predicting the behavior of a sunspot cycle is fairly reliable once the cycle is well underway (about 3 years after the minimum in sunspot number occurs prior to that time the predictions are less reliable but nonetheless equally as important. Planning for satellite orbits and space missions often require knowledge of solar activity levels years in advance.

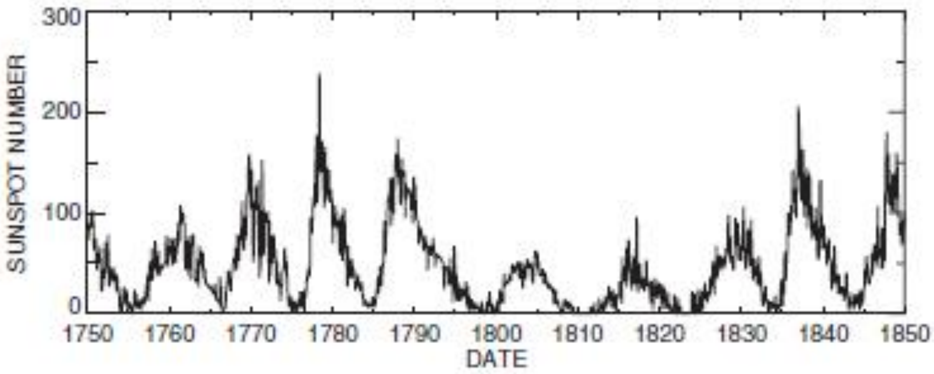
A number of techniques are used to predict the amplitude of a cycle during the time near and before sunspot minimum. Relationships have been found between the size of the next cycle maximum and the length of the previous cycle, the level of activity at sunspot minimum, and the size of the previous cycle.

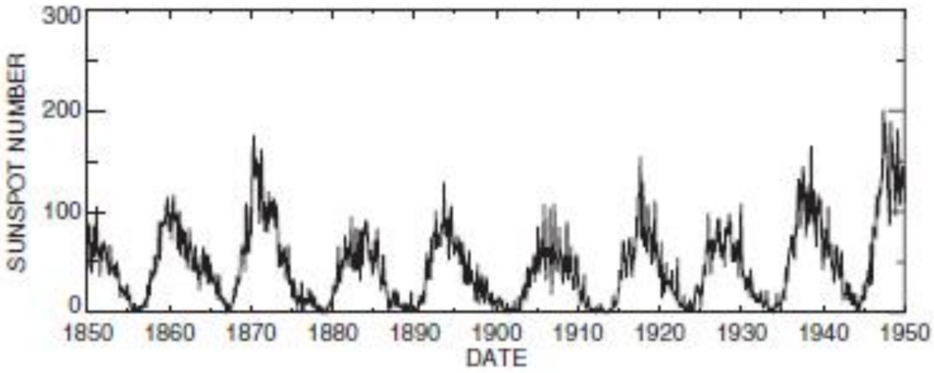
Connections between them and future solar activity levels are still uncertain. Of these "geomagnetic precursor" techniques three stand out. The earliest is from Ohl and Ohl [*Solar-Terrestrial Predictions Proceedings*, Vol. II. 258 (1979)] they found that the value of the geomagnetic *aa* index at its minimum was related to the sunspot number during the ensuing maximum. The primary disadvantage of this technique is that the minimum in the geomagnetic *aa* index often occurs slightly after sunspot minimum so the prediction isn't available until the sunspot cycle has started. An alternative method is due to a process suggested by Joan Feynman. She separates the geomagnetic *aa* index into two components: one in phase with and proportional to the sunspot number, the other component is then the remaining signal. This remaining signal has, in the past, given good estimates of the sunspot numbers several years in advance. The maximum in this signal occurs near sunspot minimum and is proportional to the sunspot number during the following maximum. This method does allow for a prediction of the next sunspot maximum at the time of sunspot minimum.

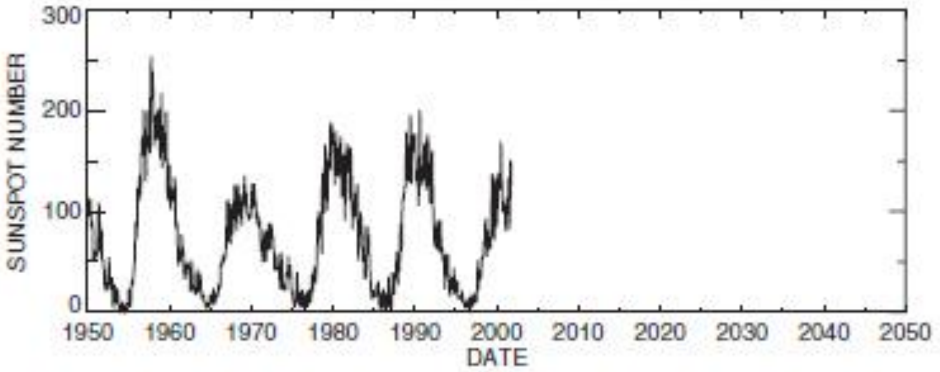
A third method is due to Richard Thompson [*Solar Physics* 148, 383 (1993)]. He found a relationship between the number of days during a sunspot cycle in which the geomagnetic field was "disturbed" and the amplitude of the next sunspot maximum. His method has the advantage of giving a prediction for the size of the next sunspot maximum well before sunspot minimum.

We have suggested using the average of the predictions given by the Feynman-based method and by Thompson's method. However, both of these methods were impacted by the "Halloween Events" of October/November 2003 which were not reflected in the sunspot numbers. Both methods give larger than average amplitude to Cycle 24 while its delayed start and low minimum strongly suggest a much smaller cycle. [9]

(2-6) Sunspots and the Solar Cycle





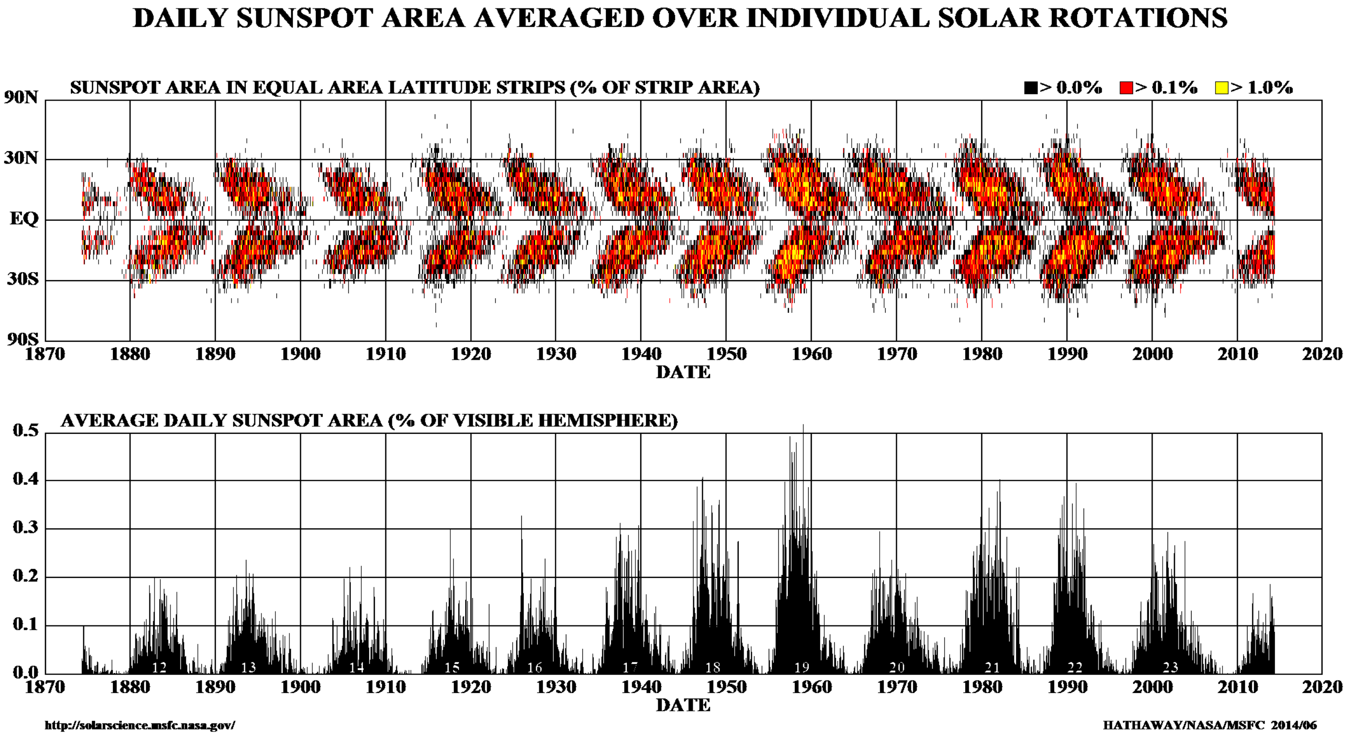


The number of sunspots changes with a 11 years period which is called the solar activity cycle. Today we know that all solar activity phenomena are related to Sunspots and thus to magnetic activity. To measure the solar activity the sunspot numbers were introduced and in order to smear out effects of solar rotation, R is given as a monthly averaged number and called the sunspot relative number. Today there exist better methods to quantify the solar activity however sunspot numbers are available for nearly 400 years and thus this number is still used. Let us briefly summarize the behavior of sunspots during the activity cycle:

- The leader spots (i.e. by convention it is defined that the Sun rotates from east to west; the largest spot of a group tends to be found on the western side and is called the leader, while the second largest in a group is called the follower) in each hemisphere are generally all of one polarity, while the follower spots are of the opposite polarity.

- If the leaders and followers are regarded as magnetic dipoles, the orientation of these dipoles is opposite on opposite hemispheres.
- The magnetic axes of the dipoles are inclined slightly towards the equator, the leader spot being closer. This inclination is about 12^0
- Towards the end of a cycle spot groups appear at high latitudes with reversed polarity, they belong to the new cycle whereas those with normal polarity for the old cycle occur close to the equator. This is illustrated in the so called butterfly diagram

Figure (2-2)



Sunspots they tend to overlap and can be identified further from the limb. They appear in increased numbers in a region prior to the emergence of sunspots and remain for a rotation or more after the spots have decayed. As it will be shown later they are important for the energy balance between sunspots and the photosphere. Faculae can be observed on the whole disk using filter grams. In that case they are often called plague and attributed to the chromosphere. Photospheric faculae are manifestations of concentrated azimuthal magnetic fields. One possibility to study sunspots and faculae at photospheric levels is to use the Ca II K line 0.05 nm off the center with a 0.015nm pass band.

Polar faculae appear as point like, bright photosphere spots near the solar limb at latitudes of 55 degrees or more (average of 65 degrees). Polar faculae tend to occur at lower latitudes (as low as 45 degrees) during the years in which there are only few observable. They can be distinguished from main zone faculae by their essentially point like and solitary appearance, in contrast to the more area and group like appearance of the main zone faculae (55 degrees or lower). Their lifetime is shorter (minutes to hours) than that for ordinary faculae. The brightest can last for a couple of days, and can be traced farther from the solar limb too. In connection with the activity cycle it is interesting to note that polar faculae are most numerous at times of minimum solar activity, which in turn might be an additional hint for their relation with the upcoming new solar cycle. [1]

(2-7) Wolf number R

The Wolf number (also known as the International sunspot number, relative sunspot number, or Zürich number) is a quantity that measures the number of sunspots and groups of sunspots present on the surface of the sun. The idea of computing sunspot numbers was originated by Rudolf Wolf in 1848 in Zurich Switzerland and, thus, the procedure he initiated bears his name (or place). The combination of sunspots and their grouping is used because it compensates for variations in observing small sunspots. This number has been collected and tabulated by researchers for over 150 years. They have found that sunspot activity is cyclical and reaches its maximum around every 9.5 to 11 years (note: Using data from SIDC for the last 300 years and running a FFT function on the data gives an average maximum at 10.4883 years/cycle).[10]

This cycle was first noted by Heinrich Schwabe in 1843.The relative sunspot number $R$is computed using the formula (collected as a daily index of sunspot activity):

$$R = k(10g + s)$$

Where

- $s$is the number of individual spots,
- $g$is the number of sunspot groups, and
- $k$is a factor that varies with location and instrumentation (also known as the *observatory factor* or the *personal reduction coefficient* K).[11]

Chapter Three

EARTH'S SPACE ENVIRONMENT

(3-1) introduction

In this chapter we introduced the earth's magnetosphere Structure which is including bow shock, magneto-sheath, magnetopause and magneto-tail; then we introduced the sun effect at magnetosphere by magnetic storms, particle motion and the aurora then we introduced the auroral electrojet (AE), k, Kp and Dst indices.

(3-2) Magnetosphere

Is the area of space near an astronomical object in which charged particles are controlled by that object's magnetic field. Near the surface of the object, the magnetic field lines resemble those of a magnetic dipole. Farther away from the surface, the field lines are significantly distorted by electric currents flowing in the plasma (e.g. in ionosphere or solar wind). When speaking about Earth, *magnetosphere* is typically used to refer to the outer layer of the ionosphere, although some sources consider the ionosphere and magnetosphere to be separate. [12]

(3-3)The Earth magnetosphere Structure

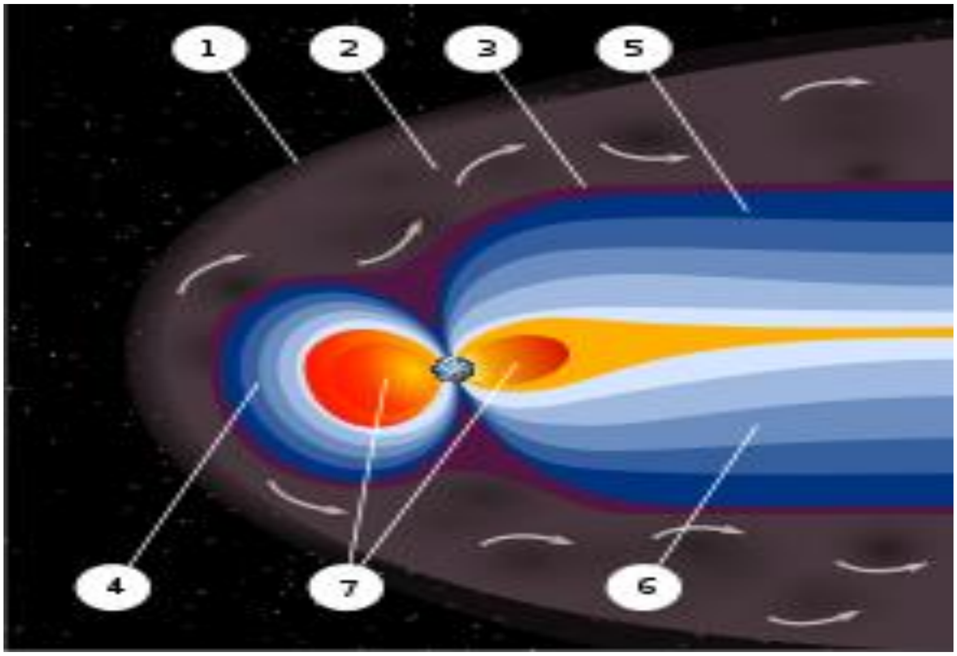


Figure (3-1):An artist's rendering of the structure of a magnetosphere:
1) Bow shock. 2) Magnetos heath. 3) Magnetopause. 4) Magnetosphere.
5) Northern tail lobe. 6) Southern tail lobe. 7) Plasma sphere.

(3-3-1) Bow shock

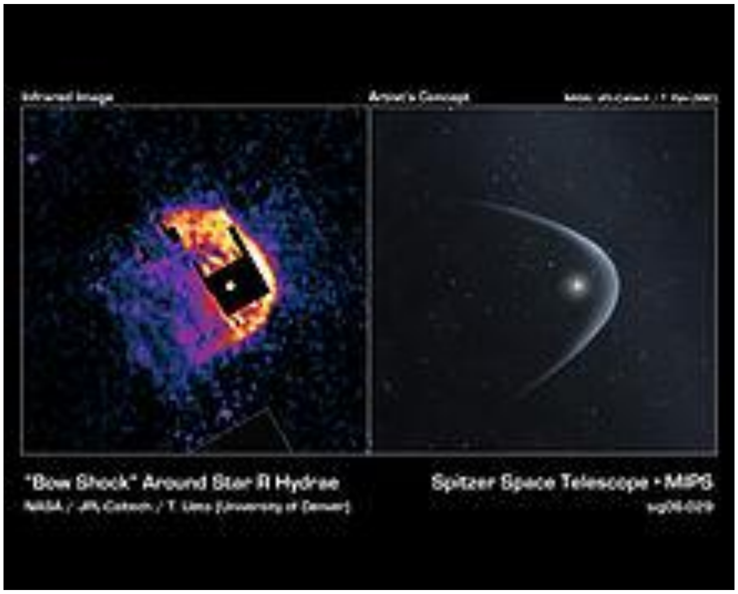


Figure (3-2) Infrared image and artist's concept of the bow shock around R Hydrae
Main article: Bow shock

The bow shock forms the outermost layer of the magnetosphere: the boundary between the magnetosphere and the ambient medium. For stars, this is usually the boundary between the stellar wind and interstellar medium; for planets, the speed of the solar wind there plummets as it approaches the magnetopause.[13]

(3-3-2) Magnetosheath

The magnetos heath is the region of the magnetosphere between the bow shock and the magnetopause. It is formed mainly from shocked solar wind, though it contains a small amount of plasma from the magnetosphere. It is an area exhibiting high particle energy flux, where the direction and magnitude of the magnetic field varies erratically. This is caused by the collection of solar wind gas that has effectively undergone thermalization. It acts as a cushion that transmits the pressure from the flow of the solar wind and the barrier of the magnetic field from the object.[6]

(3-3-3) Magnetopause

The magnetopause is the area of the magnetosphere wherein the pressure from the planetary magnetic field is balanced with the pressure from the solar wind. It is the convergence of the shocked solar wind from the magnetos heath with the magnetic field of the object and plasma from the magnetosphere. Because both sides of this convergence contain magnetized plasma, the interactions between them are very complex. The structure of the magnetopause depends upon the Mach number and beta of the plasma, as well as the magnetic field. The magnetopause changes size and shape as the pressure from the solar wind fluctuates.[14]

(3-3-4) Magneto tail

Opposite the compressed magnetic field is the magneto tail, where the magnetosphere extends far beyond the astronomical object. It contains two lobes, referred to as the northern and southern tail lobes. The northern tail lobe points towards the object and the southern tail lobe points away. The tail lobes are almost empty, with very few charged particles opposing the flow of the solar wind. The two lobes are separated by a plasma sheet, an area where the magnetic field is weaker and the density of charged particles is higher.[15]

(3-4) Earth's magnetosphere

Over Earth's equator, the magnetic field lines become almost horizontal, then return to connect back again at high latitudes. However, at high altitudes, the magnetic field is significantly distorted by the solar wind and its solar magnetic field. On the dayside of Earth, the magnetic field is significantly compressed by the solar wind to a distance of approximately 65,000 kilometers (40,000 mi). Earth's bow shock is about 17 kilometers (11 mi) thick and located about 90,000 kilometers (56,000 mi) from Earth. The magnetopause exists at a distance of several hundred kilometers off earth's surface. Earth's magnetopause has been compared to a sieve because it allows solar wind particles to enter. Kelvin–Helmholtz instabilities occur when large swirls of plasma travel along the edge of the magnetosphere at a different velocity from the magnetosphere, causing the plasma to slip past. This results in magnetic reconnection, and as the magnetic field lines break and reconnect, solar wind particles are able to enter the magnetosphere. On Earth's night side, the magnetic field extends in the magneto tail, which lengthwise exceeds 6,300,000 kilometers (3,900,000 mi). Earth's magneto tail is the primary source of the polar aurora. Also, NASA scientists have suggested or "speculated" that Earth's magneto tail can cause "dust storms" on the Moon by creating a potential difference between the day side and the night side. [15]

(3-5) Sun effect at magnetosphere

(3-5-1) Magnetic Storms

The Sun heats the Earth’s atmosphere. Also the degree of ionization in the ionosphere increases at the dayside and this causes convection in the ionosphere. By this convection charged particles are transported into the magnetosphere and by dynamo action ionospheric electric currents above the equator up to mid-latitudes are generated. These currents produce a magnetic field which moves with the sub solar point. So there is a 12 h variation for a given observing site in the measurements of the field strength. The Sun emits articles and the solar wind compresses the magnetosphere as it has been mentioned before. High speed particles further compress the magnetosphere, and a magnetic storm begins with a SSC (storm sudden commencement). The number of charged particles trapped within regions of the magnetosphere (radiation belts) is increased. These particles drift around the Earth creating a ring current that produces a depression of the horizontal magnetic field, seen at lower latitudes around the world as a magnetic storm. This is followed by the recovery

Phase, lasting one day or more, during which the ring current subsides and the magnetic field returns to normal. Charged particles are guided down the field lines into the upper atmosphere. This produces auroral electro jets (large horizontal currents that flow in the D and E regions of the auroral ionosphere) which are intense east-west currents. Associated with these currents are intense magnetic fields causing magnetic disturbances observed there.[1]

(3-5-2) Particles and Particle Motion

The solar wind sweeps toward Earth at supersonic speeds ranging from 300 to 1000 km/s. It distorts the Earth's magnetic field which forms out a comet shaped magnetosphere.

There are two Van Allen belts of particle concentration: a) small inner belt between 1 and 2 Earth radii where protons of energy 50 MeV and electrons with energies > 30MeV reside and b) utter larger belt from 3 to 4Earth radii where less energetic protons and electrons are concentrated. The inner belt is relatively stable, the outer belt varies in its number of particles by as much as a factor of 100.

Charged particles trapped in the belts spiral along the field lines while bouncing between the northern and southern mirror points. Particles in the inner belt may interact with the upper atmosphere causing the auroral oval which is an annulus centered over the magnetic poles and around 3000 km in diameter during quiet times. The location of the auroral oval is usually found between 60 and 70 degrees of magnetic latitude (north and south).

When charged particles follow magnetic field lines current flows, this is called a Birkeland current 5. Today, often the term auroral Electrojet is used. Auroral Birkeland currents can reach about 106 A and heat up the upper atmosphere which results in increased drag on low-altitude satellites.[1]

(3-5-3) Aurora

There are many shapes and features of aurorae. They generally start at 100 km above the surface and extend upward along the magnetic field for hundreds of km. auroral arcs can nearly stand still and then suddenly move (dancing, turning). After midnight one often sees a patchy appearance of aurorae, and the patches blink on and off every 10 s or so. Most of aurorae are greenish yellow and sometimes the tall rays turn red at their top and along their lower edge. On rare occasions sunlight hits on the top creating a faint blue color.

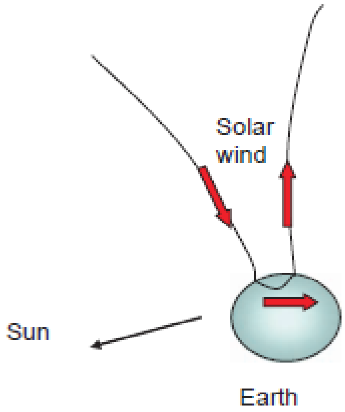


Figure (3-3): Birkeland currents. The currents flow downwards on the morning side and Space wards on the evening side.

The different colors depend on the specific atmospheric gas, its electric All state and on the energy of the particle that hits the atmospheric gas. Atomic oxygen is responsible for the two main colors of green (557.7 nm, at a height below 400 km) and red (630.0 nm, about 400 km or higher). Excited nitrogen also emits light (600-700 nm; below 200 km). Auroral displays are intensified if the interplanetary magnetic field is in the opposite direction to the Earth’s magnetic field. The geomagnetic storms produce brightness changes and motion in the aurorae and these are called auroral sub storms. Recent models of aurorae explain the phenomenon by a process of release of energy from the magneto tail, called magnetic reconnection. Regions of opposite magnetic fields come together and the magnetic field lines can break and reconnect in new combinations. The point of reconnection in the magneto tail lies usually at 100 Earth radii (see 8.7). When the solar wind adds sufficient magnetic energy to the magnetosphere, the field lines there overstretch and a new reconnection takes place at 15 Earth radii, the field collapses and electrons are injected into the atmosphere. [1]

(3-5-4) Auroral Electrojet Index (AE)

The Auroral Electrojet Index, AE, is designed to provide a global, quantitative measure of auroral zone magnetic activity produced by enhanced Ionospheric currents flowing below and within the auroral oval. Ideally, It is the total range of deviation at an instant of time from quiet day values of the horizontal magnetic field (H) around the auroral oval. Defined and developed by Davis and Sugiura [1966], AE has been usefully employed both qualitatively and quantitatively as a correlative index in studies of substorm morphology, the behavior of communication satellites, radio propagation, radio scintillation, and the coupling between the interplanetary magnetic field and the earth's magnetosphere. For these varied uses, AE possesses advantages over other geomagnetic indices or at least shares their advantageous properties.

1. it can be derived on an instantaneous basis or from averages of variations computed over any selected interval;
2. it is a quantitative index which, in general, is directly related to the processes producing the observed magnetic variations;
3. its method of derivation is relatively simple, digital, and objective and is well suited to present computer processing techniques; and
4. it may be used to study either individual events of statistical aggregates.[16]

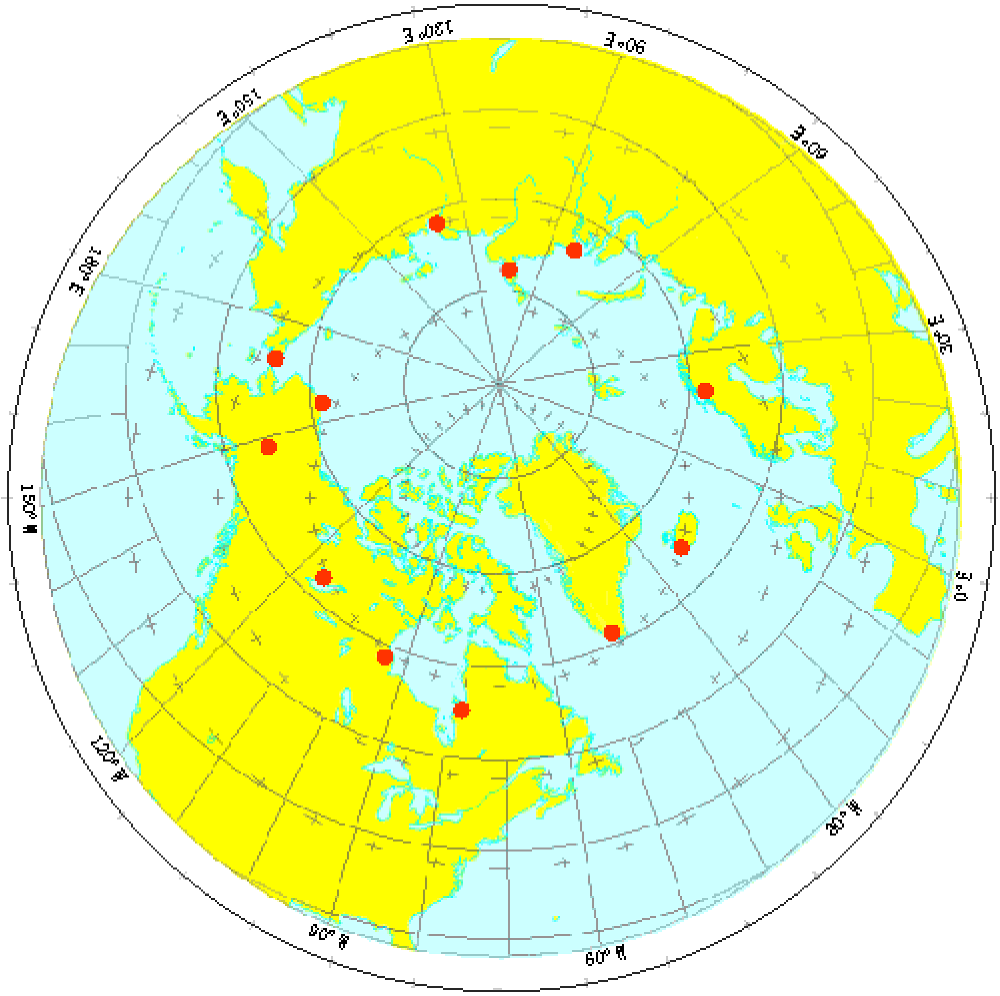


Figure (4-4) shows the observation centers used in obtaining the AE index in the earth as shown from north polar of the earth. [17]

(4-3) k-index

The K-index quantifies disturbances in the horizontal component of earth's magnetic field with an integer in the range 0-9 with 1 being calm and 5 or more indicating a geomagnetic storm. It is derived from the maximum fluctuations of horizontal components observed on a magnetometer during a three-hour interval. The label 'K' comes from the German word 'Kennziffer' meaning 'characteristic digit.' The K-index was introduced by Julius Bartels in 1938. [18]

(4-4) Calculation of K-index

The K-scale is quasi-logarithmic. The conversion table from maximum fluctuation R (nT) to K-index, varies from observatory to observatory in such a way that the historical rate of occurrence of certain levels of K are about the same at all observatories. In practice this means that observatories at higher geomagnetic latitude require higher levels of fluctuation for a given K-index. For example, at Godhaven, Greenland, a value of K equal to 9 is derived with R=1500 nT, while in Honolulu, HI, a fluctuation of only 300 nT is recorded as K=9. In Kiel, Germany, K=9 corresponds to R=500 NT or greater. The real-time K-index is determined after the end of prescribed three-hour intervals (0000-0300, 0300-0600... 2100-2400). The maximum positive and negative deviations during the 3-hour period are added together to determine the total maximum fluctuation. These maximum deviations may occur any time during the 3-hour period.[19]

(4-5)The Kp index and estimated Kp index

The official planetary Kp index is derived by calculating a weighted average of K-indices from a network of geomagnetic observatories. Since these observatories do not report their data in real-time, various operations centers around the globe estimate the index based on data available from their local network of observatories. The Kp-index was introduced by Bartels in 1939. [19]

(4-6) Disturbance storm time index (D_{ST})

The disturbance storm time (D_{ST}, Kyoto Dst) index is a measure in the context of space weather. It gives information about the strength of the ring current around Earth caused by solar protons and electrons.

The ring current around Earth produces a magnetic field that is directly opposite Earth's magnetic field, i.e. if the difference between solar electrons and protons gets higher, then Earth's magnetic field becomes weaker.

A negative Dst value means that Earth's magnetic field is weakened. This is particularly the case during solar storms. [20]

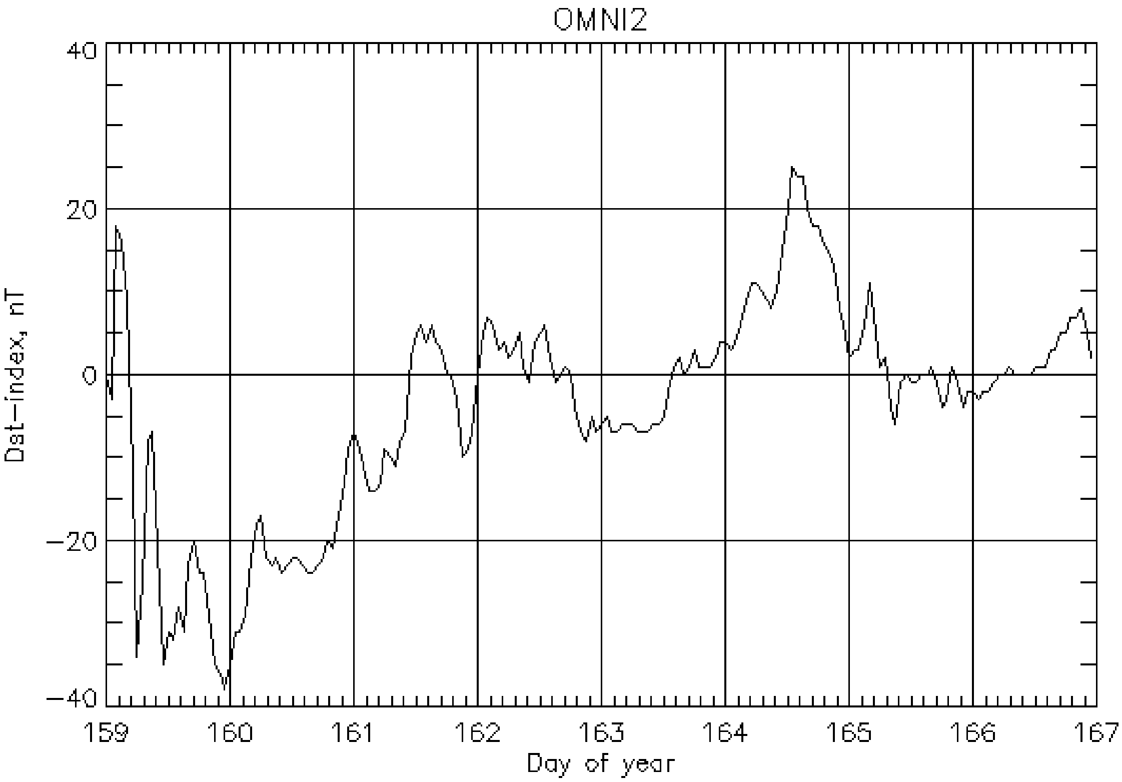


Figure (4-1) shows the DST index within a week for June 2014.

Chapter four

OBSERVATION RESULTS

(4-1) data and graphs

In this chapter we introduced observational results of sunspot R, Dst, AE and Kp indices, and the data were obtained from Omni website:
http://omniweb.gsfc.nasa.gov/form/dx1.html
The data covered one solar cycle, that is: solar cycle 23.

Time series plots of Kp, R index, Dst, and AE indices within a period of one solar cycle were stacked to show the link between those parameters.

The following figure (4-1) shows the stacked plots of Kp index, R index, Dst index and AE index within a period of one solar cycle. We extracted similar plots for start month of two solar cycles, i.e. solar cycle 23rd and solar cycle 24th. Figures (4-2) and (4-3) show those extracted plots.

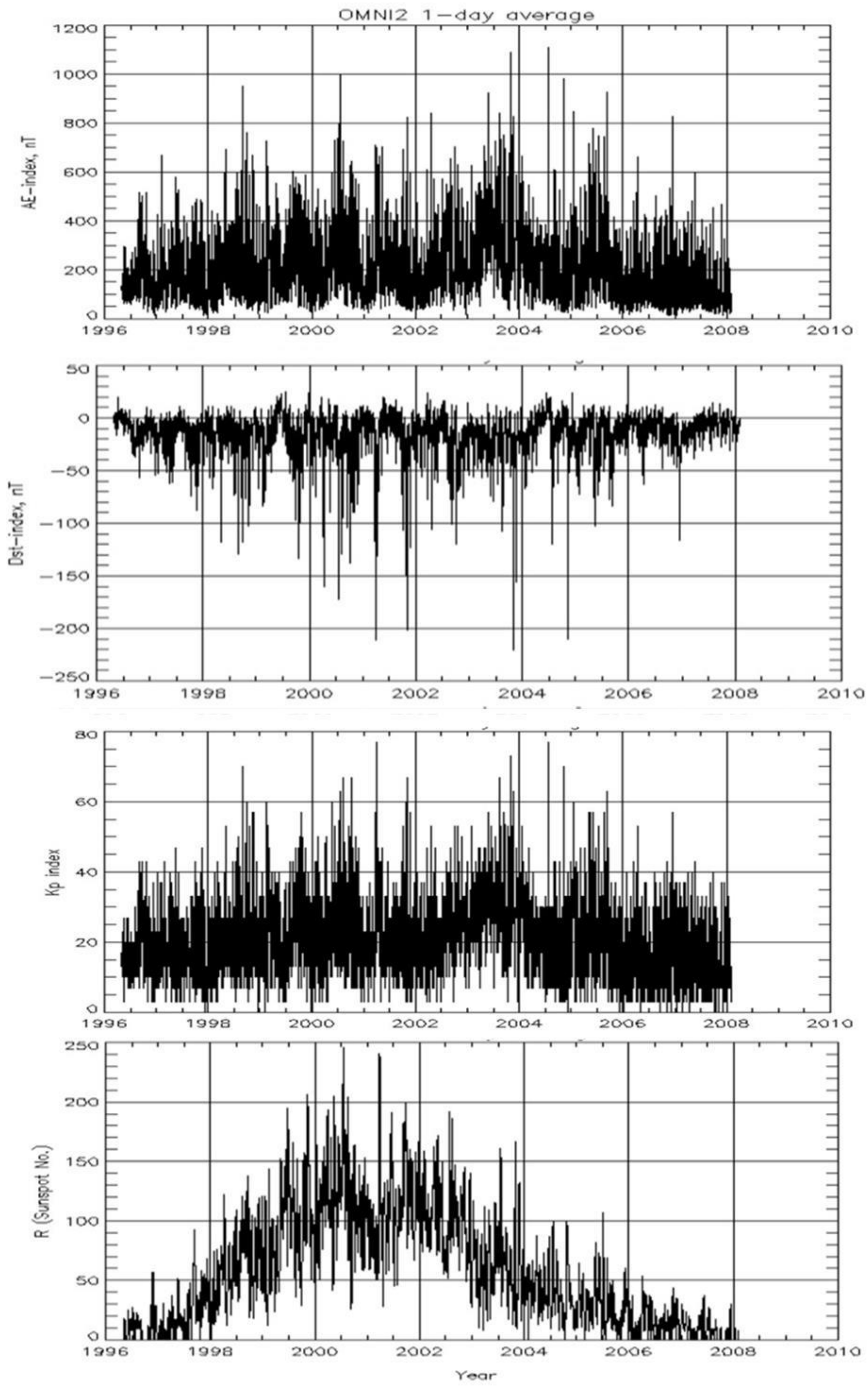


Figure (4-1) shows the R, Kp, D_{st} and AE indices for one solar cycle(i.e. cycle 23).

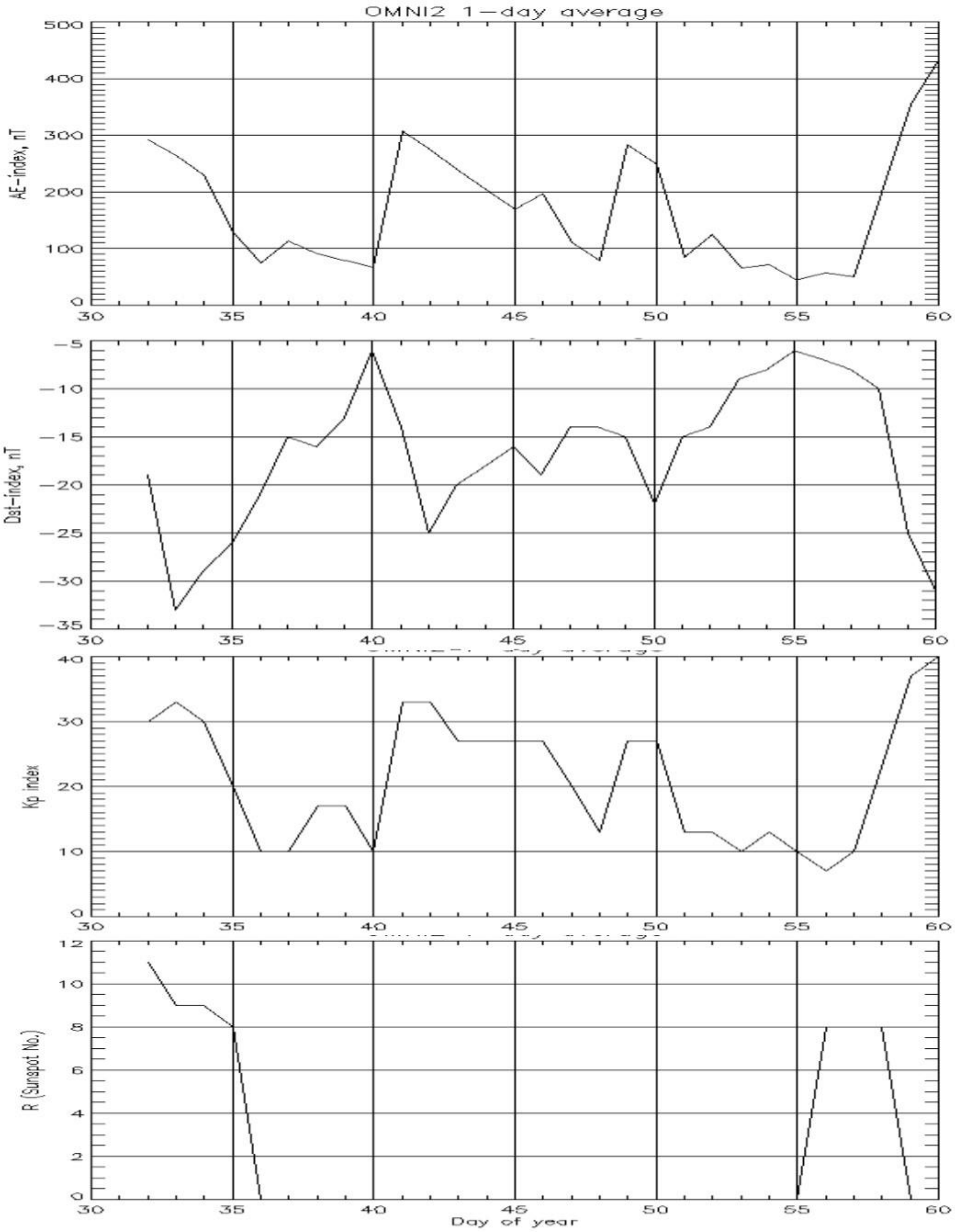


Figure (4-2) shows the R, kp, Dst and AE indices within a period of one month, i.e. May 1996 the beginning of solar cycle 23.

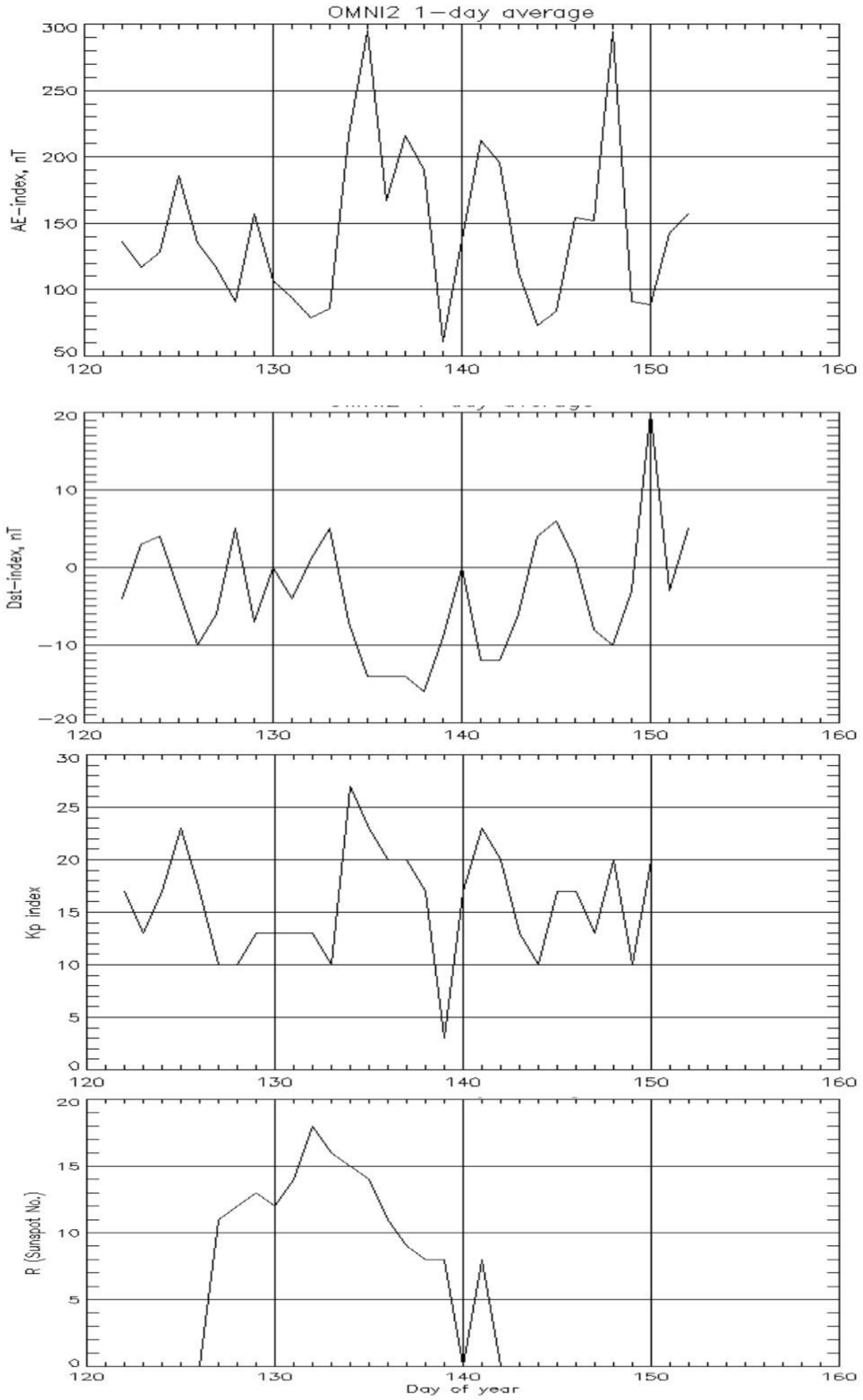


Figure (4-3) shows the R, kp, Dst and AE indices within a period of one month, i.e. February 2008 the beginning of solar cycle 24.

We can see from figure (4-2): the data are of one month of solar cycle 23 and figure (4-3): the data are of one month of solar cycle 24 that geomagnetic indices depend on sunspots number (R-index).

At the beginning of the solar cycle the number of sunspots starts in minimum level so the other geomagnetic indices will be at minimum levels too. but at mid of cycle the sunspots number gets at maximum levels so the Dst-index will take a negative values which is mean solar storms at high level and the magnetic field of the earth is weakened by solar storms. The auroral electrojet (AE) auroral zone geomagnetic activity gets at high levels.

Chapter five

DISCUSSION AND CONCLUSION

Discussion

One interesting aspect of the Sun is its sunspots. Sunspots are areas where the magnetic field is about 2,500 times stronger than Earth's, much higher than anywhere else on the Sun. Because of the strong magnetic field, the magnetic pressure increases while the surrounding atmospheric pressure decreases. This in turn lowers the temperature relative to its surroundings because the concentrated magnetic field inhibits the flow of hot, new gas from the Sun's interior to the surface. Sunspots tend to occur in pairs that have magnetic fields pointing in opposite directions. A typical spot consists of a dark region called the umbra, surrounded by a lighter region known as the penumbra. The sunspots appear relatively dark because the surrounding surface of the Sun (the photosphere) is about 10,000 degrees F., while the umbra is about 6,300 degrees F. Sunspots are quite large as an average size is about the same size as the Earth. In just a few minutes, the flares heat to several million degrees F. and release as much energy.

On regarding the geomagnetic indices it is customary to note that: Kp-index measures the conditions near Earth, Dst-index measures the disturbance on the storm time directly and AE-index measures the Electrojet substorm. Because the sunspots can drive magnetic perturbations in the Earth’s space environment it is conceivable the relation between sunspots and the Kp-index, which could measures the conditions on the near-Earth’s environment. Also conceivable the relation between Kp index and the other storm and supstorm geomagnetic indices, i.e. Dst and AE indices.

Our result is a viewable correlation between the sunspot R-index and the Kp-index, consequently a correlation between R-index and the other storm and supstorm geomagnetic indices, i.e. Dst and AE indices, figure (4-1) shows these correlations for a long-term data (a one solar cycle, i.e. cycle 23)

Conclusion

Observation of sunspots is very important because of the impact on Earth’s space environment, this could be manifested in the sever perturbations on the magnetic field and consequently the occurrence of the geomagnetic storms at the Earth.

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