Ionosphere Properties and Behaviors - Part 10

By Marcel H. De Canck, ON5AU

As mentioned in the previous chapter the aurora properties at the polar zones can play a significant role to our radio waves propagations, not only skewing the path of the lowest ham-bands but also attenuation and totally absorption might take place at higher frequencies. In contrast, the VHF frequencies can display frequently side and back scatter, allowing much longer distance contacts.

What is the origin or the onset to the auroral phenomenon? In this and the forthcoming issue I shall unveil some aurora characteristics and properties and their impact at various frequency bands.

The interplanetary Medium and Magnetic Fields

The aurora phenomenon is related to the geomagnetic activity, disturbances, and storms caused by solar violating behavior. Knowing the mechanism and origin to these disturbances and having access to measurements to interpret them is a must to have insight to radio wave behavior for communication circuits at, near, and traversing the polar zones.

The auroral activity is best known as the visual ***Northern*** and ***Southern light***, respectively named: the ***Aurora Borealis*** and the ***Aurora Australis.*** The origin of the auroral phenomenon is the Sun where plasma is ejected in the form of the solar wind. Coronal holes and regions of open magnetic fields are important sources of enhanced solar wind. The solar wind travels into space at velocities, near earth, ranging from 200 to 900 km/sec with an average of 450km/sec. On the average, the transit time between sun and earth is about 4½ days, during which time the sun rotates through about 60º. The plasma coming from the sun's corona is called the interplanetary plasma; the plasma that is trapped within the earth's magnetic field is the Magnetospheric plasma. The magnetic activity, here on earth, results from the impact of the solar wind on the magnetosphere and the coupling of the solar interplanetary magnetic field with the earth's magnetic field.

The solar interplanetary magnetic field (IMF) lines are dragged out into interplanetary space. But because the sun rotates, these field lines are dragged out in an Archimedes-type spiral pattern. For an observer on the earth, the plasma expands radially while the field lines form spirals with the foot points anchored to the Sun itself. Conversely, for an observer on the Sun, the plasma would flow along the spiral patterns formed by the field lines, **Fig. 60.1a** and **60.1b.**

The earth's magnetic field has always the same magnetic polarity (dipole magnet type). The magnetic North Pole lies about 11º south of the geographic North Pole and 71º west of Greenwich. The magnetic South Pole is situated 12º north of the geographic South Pole and 111º east of Greenwich. The earth's magnetic field lines behave totally differently depending on the half part facing toward or back from the sun. At the daylight side, facing the sun, the magnetic field lines are depressed by the pressure of the sun's wind forces, creating a bow shock. The grade of depression depends self-evidently on the solar wind velocity and can vary quite a lot in even a short period of time. At the opposite half, the dark side, the earth magnetic field lines are forming an elongated shaped tail, **Fig. 60.2a.** When we look into the tail we see the field lines stretched out: some of those near the outer edge remains open, others more inside are connected. Near the earth, in the stronger closed field, we would see two belts of trapped plasma, called the ***"Van Allen belts"***. Further out, just inside the magnetopause and normally about 20 earth radii down tail, we would see that there are really two parts to the magnetic field. We notice a north-seeking one over the northern hemisphere and a south-seeking one over the southern hemisphere. Between them is a neutral zone or sheet aligned with the magnetic equator. Often the two seeking magnetic fields connect in that neutral zone.

At the same time that we see the magnetic field lines and the neutral sheet filled with drifting solar plasma, we would be conscious of massive electrical ring currents flowing across the neutral sheet and magnetotail currents both up and down around the inside of the magnetopause boundary. These currents have to be driven by a potential and this comes from the "Lorentz forces". This force is exerted on moving charged particles as they cross a perpendicular magnetic field and it causes the charged particles to move in a circular pattern, the electrons one way, the protons the other way. As each particle has a forward momentum, its path tends to become a helix aligned with the field lines. If a coupling between the solar wind plasma's magnetic field and the earth's magnetic field is of ***South*** polarity, then we find massive amounts of particles being injected into the magnetotail regions, **Fig. 60.2b** and **60.2c.** The electrons are deflected one way and protons the other. It is the same process as "Magneto-hydrodynamic generation". On the evening side of the earth, about the equatorial neutral sheet, there is a pile-up of electrons, creating a negative charge and on the morning side a pile-up of protons, creating a positive charge. A massive electric potential therefore builds up, which drives the magnetotail currents round. These tail electric currents create magnetic fields of their own, which can modify the earth's magnetic field lines. When conditions are such that these currents are considerably increased by disturbed conditions and massive input of solar plasma, then the tail field lines can become considerably distorted.

Fig.60.1a. *The interplanetary picture.*

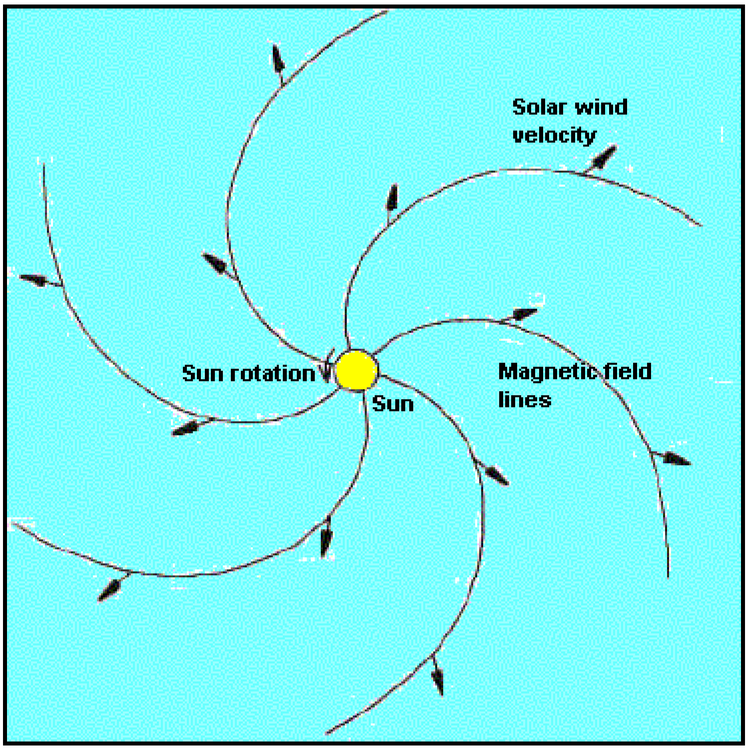


Fig.60.1b. *The spiral dragged out magnetic field lines into space.*

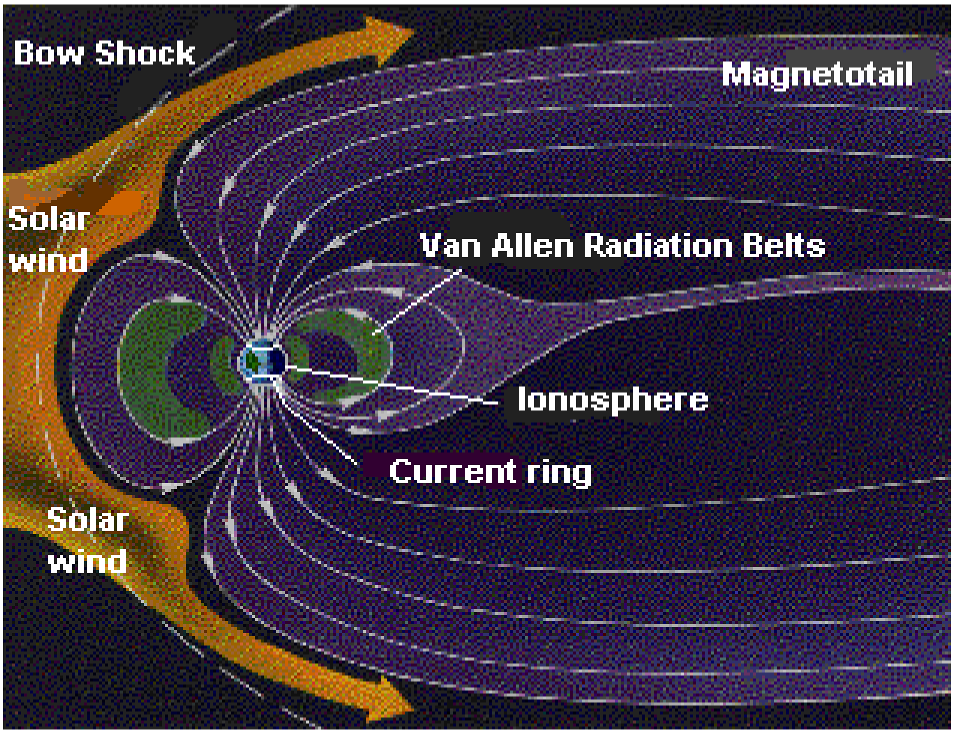


Fig. 60.2a. *The earth's magnetic field, as depressed and elongated by solar wind*

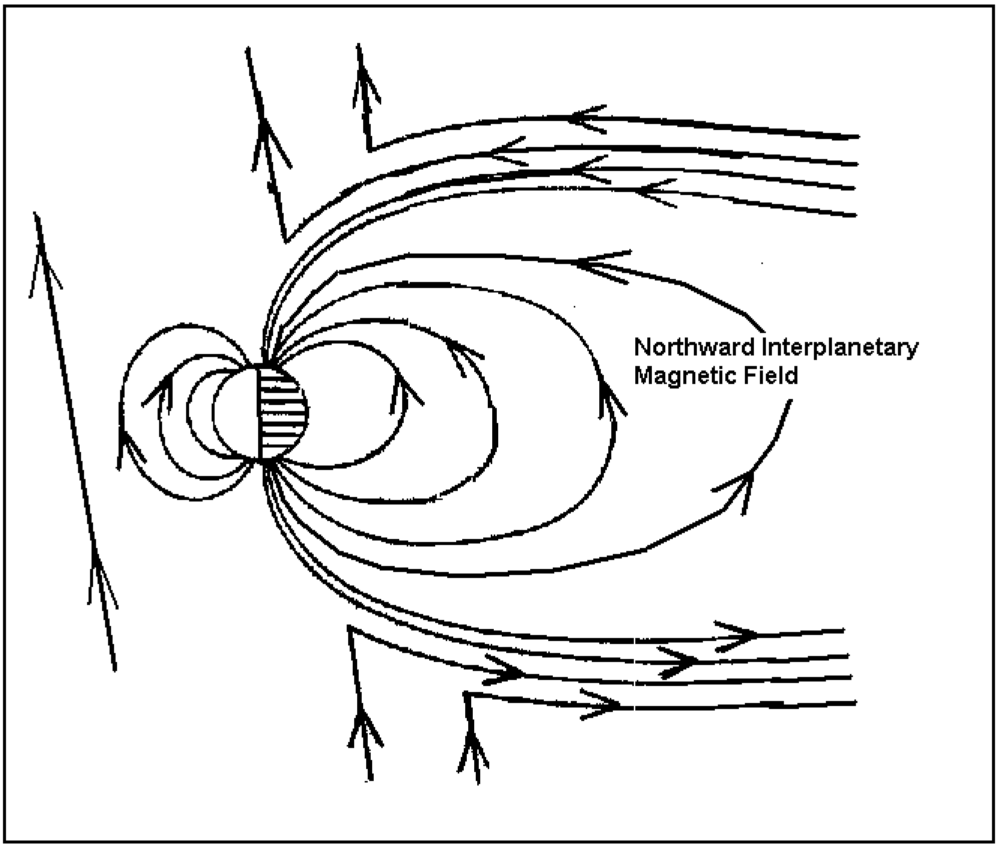


Fig. 60.2b. *Northward Interplanetary Magnetic field, no coupling occurs with the earth's magnetic field lines.*

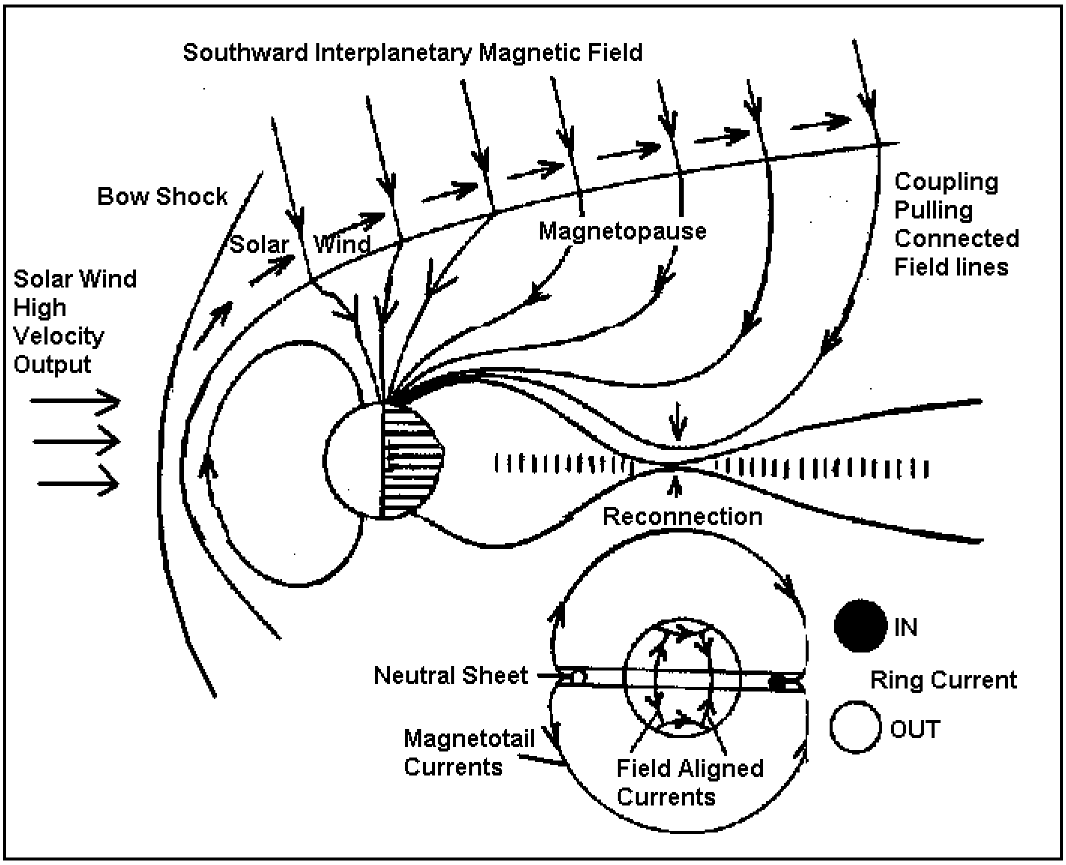


Fig. 60.2c. *Massive amounts of particles are captured and injected into and by the earth magnetic with Southward Interplanetary magnetic field.*

Why and when Northward and Southward field lines?

The interplanetary magnetic field has a spiral form and the field can be as mentioned above, directed either toward or away from the sun, giving rise to a sector structure. This sector structure has its origin in the sun's inclination (7.5º) seen from the earth and the interplanetary field line directions are opposite for both half sun hemispheres. There are even numbers of sectors, with half having the magnetic field pointing inward and half pointing outward. The number of sectors varies with the sunspot cycle and sun disturbances.

The heliospheric current sheet was used in a "ballerina" model that was first theorized by Hannes Alfvén in 1977. This model has since become a popular way of visually illustrating the structure of the heliospheric current sheet. **Figure 60.3** shows the current sheet as a warped disc-like feature somewhat similar to a ballerina's skirt. The Sun at the centre rotates counter-clockwise and drags the magnetic field lines from the photosphere into interplanetary space. The northern solar polar region in this example might have a positive (or outwardly directed) magnetic polarity. The southern hemisphere has the opposite, a negative (or inwardly directed) magnetic field polarity. This magnetic polarity direction depends on the ±11 year solar cycle. The solar wind and the interplanetary magnetic field reach far out in space both fall far below the ecliptic plane (or the plane of rotation of the Earth's orbit around the Sun). The rotation of the Sun with is inclination axis angle and its accompanying current sheet therefore makes it possible for the Earth, depending if its orbit is above or below the sun equator plane, to pass through the heliospheric current sheet and into regions of positive or negative IMF polarity.

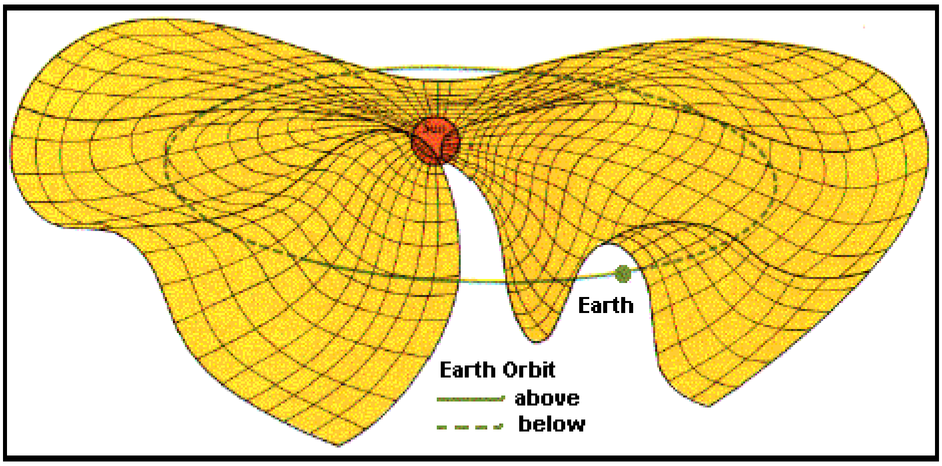


Fig. 60.3. *The 3-dementional "Ballerina" sector model.*

The interaction of both magnetic fields, the interplanetary and the earth's, plus dynamo effects, is rather complex and still not completely understood and is intensively studied. But sudden violent coronal solar mass ejection, accompanied by high velocity solar winds that create shock waves hitting the earth's magnetic field, causes the ejected charged solar particles to spiral downward around the earth's magnetic field lines to enter the polar zones. There they often create the fascinating polar light in the ionosphere above the E-zone, but they also ionize the E-layer zone to very high electron densities. The formation of the highly ionized E-zone has more or less the shape of an oval and its width and latitude location is related to the grade of the created magnetic storm, **Fig. 60.4**. **S**ee the next issue for more auroral oval properties.

Note: More solar phenomenon and properties playing a significant role to our radio wave propagation will be explained in detail in a future coming series.

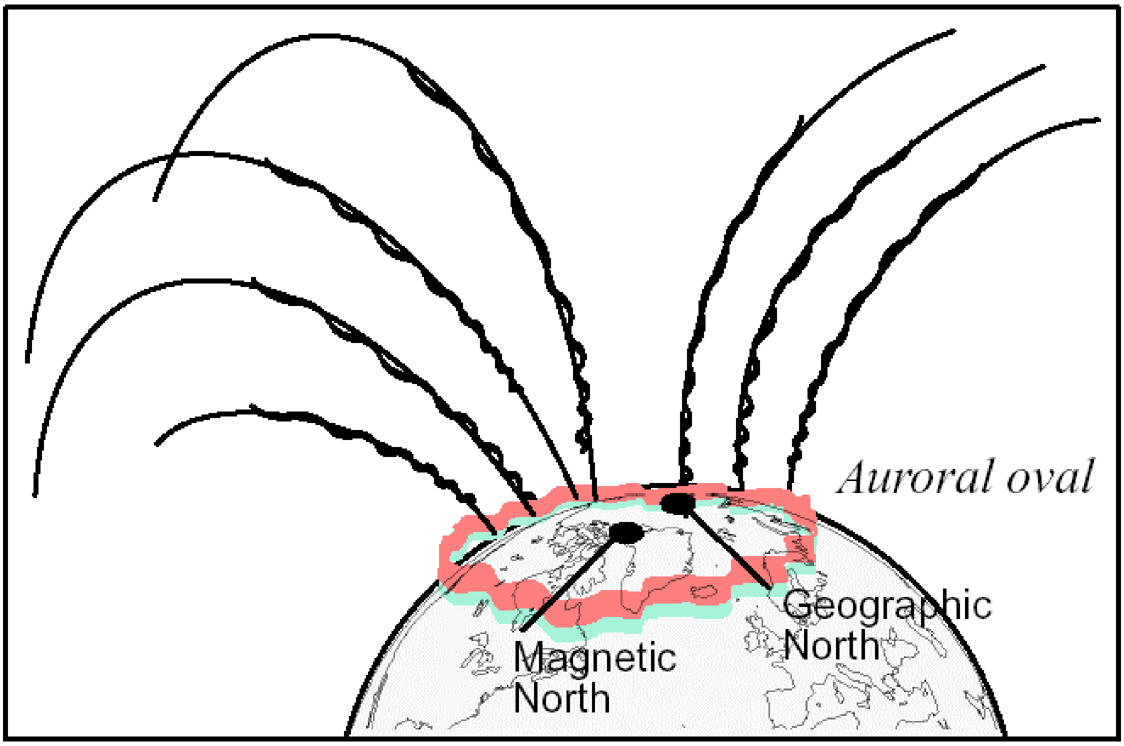


Fig. 60.4. *The helical spiraling charged particles are entering the polar zone forming the highly ionized auroral oval belt.*

Magnetic Disturbances

The A and K Indexes

The most common way to quantify the level of geomagnetic activity is through the A and K indices, available at various websites. But you will find some quite different definitions and perhaps be a bit confused.

- **The local K-index.** There are a number of worldwide observatory stations and since magnetic field measurements vary greatly depending on the location, the raw measurements are normalized to produce a K index specific to each observatory. The local K index indicates the magnitude of irregular variations in the magnetic field over three-hour intervals (0000-0300, 0300-0600, …, 2100-2400). The K-index scale is quasi-logarithmic, increasing as the geomagnetic field becomes more disturbed. The K indices range in value from 0 to 9. The numeric code is related to the maximum fluctuation **(nT)** on a magnetometer relative to a quiet day. The conversion fluctuation (nT) to K-index varies from observatory to observatory location. In practice this means that observatories at higher geomagnetic latitude require higher levels of fluctuation for a given K-index, **Table 60.1,** is the conversion table for the Boulder observatory magnetometer.

K	nT
0	0 – 5
1	5 – 10
2	10 – 20
3	20 – 40
4	40 – 70
5	70 – 120
6	120 – 200
7	200 – 330
8	330 – 500
9	> 500

Table 60.1. *Boulder conversion table*

- **The local A-index.** The concept of the A-index is to provide a longer term picture of geomagnetic activity. The A-index was invented because there was a need to derive some kind of daily average level for geomagnetic activity. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take averages of a set of K indices. What is done instead? Each K value is converted back into a linear scale called the "equivalent three hourly range", the a-index (note the lower case). So, the daily A index is merely the average of eight a-indices. **Table 60.2** illustrates the conversion between **"K "**and **"a"**

K	a
0	0
1	3
2	7
3	15
4	27
5	48
6	80
7	140
8	240
9	400

Table 60.2. *Conversion between K and a.*

Thus, for example, if the K indices for a day were **3 4 6 5 6 3 2 1**, than the daily A-index is the average of the equivalent amplitudes:

A = (15 + 27 + 80 + 48 + 80 + 15 + 7 + 3) / 8 = 34.375

- **Planetary Kp-index and Ap-index.** The official planetary **Kp** index is derived by calculating a weighted average of K indices from 13 geomagnetic observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude. The scale is 0 to 9 expressed in thirds of a unit, (e.g. **5-** is **4 2/3** and **5o** is **5** and **5+** is **5 1/3**.) They also use a 3-hour-range index and are designed to measure solar particle radiation by its magnetic effects

The 3-hourly **ap** equivalent range index is derived from the **Kp** index as shown in **Table 60.3a** and **60.3b.**

Kp	0o	0+	1-	1o	1+	2-	2o	2+	3-	3o	3+	4-	4o	4+
ap	0	2	3	4	5	6	7	9	12	15	18	22	27	32
Kp	5-	5o	5+	6-	6o	6+	7-	7o	7+	8-	8o	8+	9-	9o
ap	39	48	56	67	80	94	111	132	154	179	207	236	300	400

Table 60.3a. *The equivalent range for conversion of planetary* ***ap*** *index to* ***Kp*** *index.*

Ap	Kp
0 - 2	0
3 – 5	1
6 – 10	2
11 – 20	3
21 – 35	4
36 – 61	5
62 – 102	6
103 – 166	7
167 – 268	8
> 269	9

Table 60.3b.

The Geomagnetic activity expressed by terms in English instead of numbers

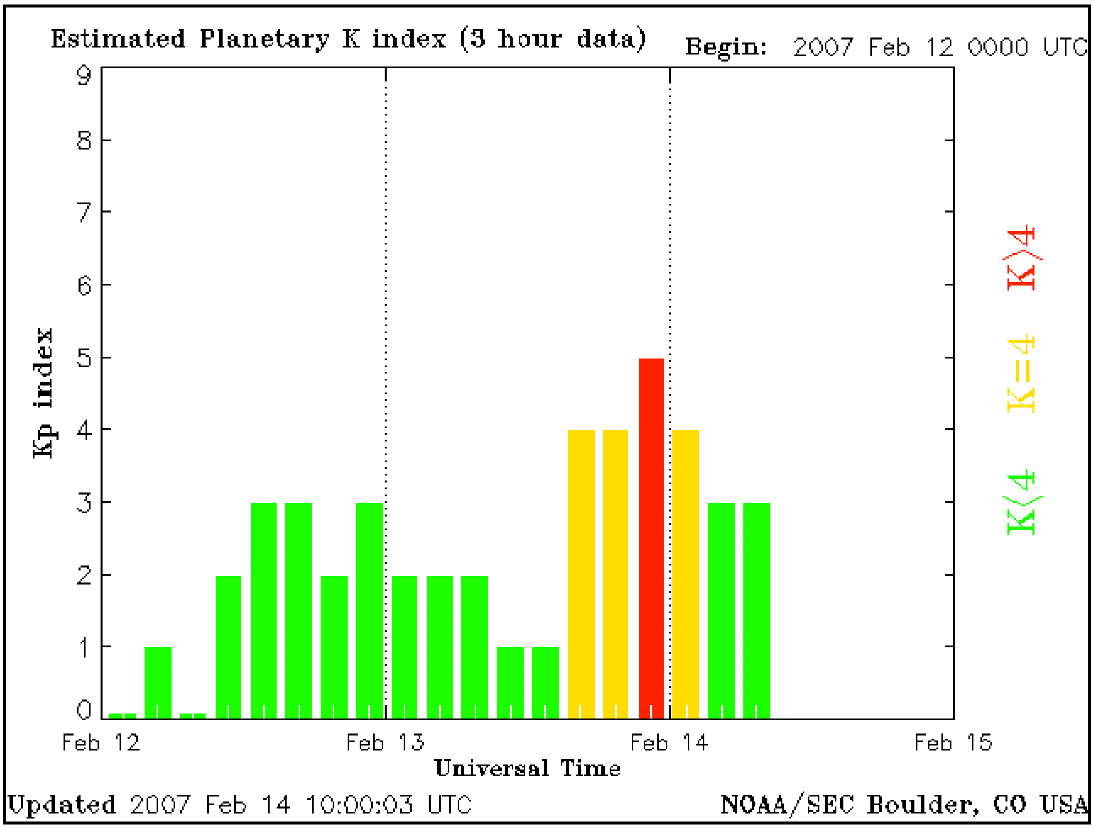
Six standard English terms are used to report geomagnetic activity and natural variations in the geomagnetic field. The terminology is based on the estimated A index for the 24-hour period directly preceding the time the broadcast was last updated. See **Tabel 60.4** for a list of the used terms.

A index Range	Geomagnetic Activity
0 – 7	Quiet
8 – 15	Unsettled
16 – 29	Active
30 – 49	Minor Storm
50 – 99	Major Storm
100 - 400	Severe Storm

Table 60.4.

Date	A	Middle Latitude Fredericksburg Local K-indices	A	High Latitude College Local K-indices	Ap	Estimated Planetary Kp-indices
2007 02 01	7	3 2 2 2 1 1 2 2	20	5 3 3 5 3 1 2 2	8	3 2 3 3 1 1 2 2
2007 02 02	2	0 0 1 0 1 2 0 1	3	1 1 1 2 1 1 1 0	2	1 1 1 0 0 1 1 1
2007 02 03	1	0 2 1 0 0 0 0 0	2	1 1 1 1 0 0 1 0	3	1 2 0 0 1 0 0 1
2007 02 04	2	0 0 2 1 0 1 1 1	3	0 0 2 3 0 0 0 0	2	0 0 1 1 0 0 1 1
2007 02 05	4	1 1 2 1 1 1 1 2	7	0 0 2 2 4 2 1 1	6	1 1 1 1 2 2 2 2
2007 02 06	6	1 2 3 2 1 1 1 1	10	1 3 3 3 3 1 1 2	8	1 3 3 3 1 0 1 1
2007 02 07	8	2 1 2 2 2 2 3 2	18	1 2 3 5 5 2 2 2	10	3 2 3 3 2 2 3 2
2007 02 08	6	2 2 2 2 2 2 1 1	14	3 1 3 5 3 3 1 0	7	2 3 2 2 1 2 1 1
2007 02 09	3	1 2 2 1 0 1 1 0	4	2 1 1 3 1 1 0 0	4	1 2 2 1 0 0 1 1
2007 02 10	2	2 1 0 0 0 1 0 1	4	1 2 0 2 0 2 1 1	3	1 1 0 0 0 1 1 1
2007 02 11	1	0 1 0 0 0 0 1 1	1	0 0 0 1 0 0 1 1	2	0 1 0 0 0 0 2 2

Example of A, K and Kp data available at NOAA website, with real-time and history choice.



Example graph of the real-time Kp-index available at the NOAA website.

Some Internet links to have access to real and previous indexes.

http://www.sec.noaa.gov/ftpdir/indices/DGD.txt

http://www.sec.noaa.gov/rt_plots/kp_3d.html

http://www.dxatlas.com/IonoProbe/

In the next issue I shall continue with the aurora oval belt phenomenon and properties, satellite observations and its impact on radio wave propagations. Stay tuned. **–30-**