Magnetic storms

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29th October 2008

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1 Are magnetic storms some kind of weather?

Hearing the word storm one may thinks of some kind of meteorological phenomenon. But in contrast to the meteorological weather a magnetic storm doesn't have his origin in the troposphere near the surface of Earth. Its setting is located in the magnetoshere. So it takes place in space, that's why magnetic storms are space weather phenomena. Nevertheless like meteorological weather similarly space weather is caused by the influence of the sun and can effect our live on Earth.

2 How humans recovered space weather

Magnetism is a phenomenon humans already know for a very long time and also space has been observed through the hole history of humanity. But relating these two physical categories is the key to the understanding of space weather and thereby magnetic storms.
In the 18th century Celsius and Hiorter were the first who associated disturbances of the Earth's magnetic field with the appearance of aurorae by unusual motion of a compass needle.
The sunspot cycle developed by the pharmacist Schwabe between 1826-1838 was later suspected to be related to the variations of the Earth's magnetic field. But the correlation between the number of sun spots and magnetic storms, how disturbances in the magnetic field of the Earth are called, was only found for long-term monitoring. On a short-term scale the correlation failed. Later more indications for solar activity like solar flares were observed, which were regarded as further possible reasons for magnetic disturbances on Earth by different scientist. But still the assumed correlation wasn't proved clearly.

Long-term studies and spectroscopical made images of the sun possible due to the invention of the specroheliograph in 1892 by Hale promoted that there were more events of the sun's activity observed and a better recording of these events was made.
Maunder figured out that the sun must be the origin of magnetic storms based the correlation between these storms and not only the sun spot cycle but the rotation cycle of the sun as well in 1904. The interpretation of these results was conform with the corpuscular hypothesis suggested earlier which proposed the radiation of particles from the sun out into space. Birkland tried to show with his "terella" experiment that it is possible that activities of the sun could cause a varying stream of electrons with high velocities which influences the Earth's magnetic field by hiting it. The idea of a stream caused by the sun was enhanced into the concept of an equally devided composition of negatively and positivly charged particles.
This led to the theory of a cavity around Earth formed by the geomagnetical field which doesn't allow the stream particles to enter, the magnetosphere, proposed by Chapman and Ferraro in 1931.
At roughly the same time the appearance of magnetic storms was detected to be periodical for weak storms and irregular for strong storms. The weak periodical storms seemed to be related to so called M regions which are not related to visible events like solar flares but to the rotation cycle of the sun.
Around 1920 Hale advanced his spectroheliograph to a spectohelioscope which enabled visual observations of the sun at different wavelength. Henceforward solar flares could be observed in detail and the corelations between them and the irregular magnetic storms were made.
At least measurements of early space crafts helped to figure out that the so called M regions are coronal holes ejecting a fast solar wind due to open field lines of the magnetic field of the sun and that eruptions like solar flares and coronal mass ejections are the reason for the more irregular and strong storms.

3 What happens out there?

As we now know a magnetic storm is a disturbance of the Earth's magnetic field caused by variations of the solar wind, a plasma consisting of charged particles streaming radial away from the sun, which are related to the activity of the sun.

Based on the frozen-in concept of plasma and magnetic field lines which describes the flow of a plasma determined by a magnetic field and the "motion" of magnetic field lines carried by a plasma flow the solar wind carries the magnetic field of the sun out into space and towards the Earth.
Since we understand that the solar wind carries the sun's magnetic field, it is clear that there must be some interaction between this field and the roughly dipolar magnetic field of the Earth when the solar wind approaches.
The result of this interaction is Earth's magnetosphere which represents an equilibrium state between the interplanetary magnetic field (IMF) and the geomagnetical field. The magnetosphere with its compressed profile on the day side and its extended profile called magnetotail on the night side shaped by the solar wind includes different futher dynamically formed fields and currents in the magnetosphere and the upper atmosphere of our planet.
In general the field lines of the magnetosphere are not conected to the magnetic field lines of the IMF so that there is a sharp boundary between both fields called the magnetopause. Applying Ampere's law the sharp boundary creates magnetopausecurrents in different directions on the day and night side of Earth.
In the inner magnetosphere a ring current due to the field gradient caused drift of the plasma particles in the magnetospere is rofmed. And there are field aligned currents induced by the influence of the magnetic field on sunward flowing plasma outside the corotating amtmospheric layers from the tail.

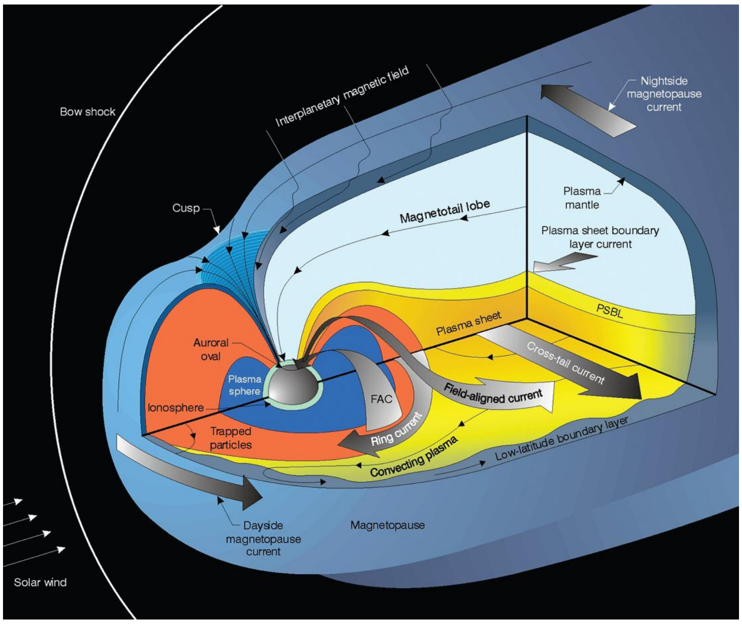

Figure 1: schematical image of the magnetosphere and its included fields, currents and plasma flows

In equilibrium there are mainly no variations in the magnetic field of the Earth and it is not possible for solar wind particles to enter the magnetosphere because of the sharp boundary between the magnetic fields. Only when the solar wind varies in intensity or the solar wind carried IMF points southward the magnetosphere and all the linked up dynamically formed fields and currents could be influenced in a powerful way and world wide partly damaging effects could be caused.

One effect that a stronger solar wind has is the compression of the day side magnetosphere and the extension of the magnetotail. The effect is that a plasma heating that could cause the expansion of the upper atmosphere takes place and that the ring current is strengthend as well.

A variation of the IMF through changing to a southward and thus antiparallel orientation compared to the Earth's magnetic field weakens the boundary between the magnetic field of the Earth and the IMF and allows magnetic reconnection on the day side. The reconnedted magnetic field lines acting like rubber bands free the field stored energy by pushing the plasma backwards in the direction of the magnetotail. Here another reconnection could take place between unshut field lines which accelerates plasma of the tail towards Earth. The plasma motion gives rise to the ring current and causes aurorae by hiting the ionosphere due to the flow along the field aligned electric field.

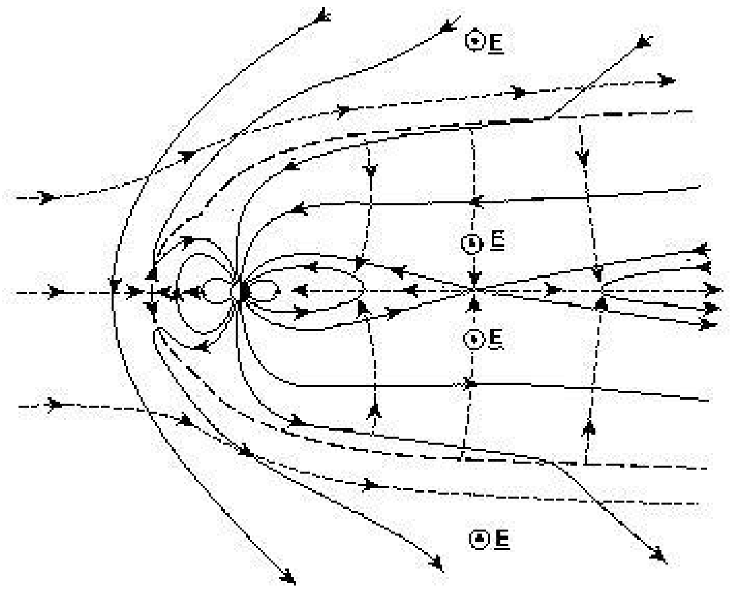

Figure 2: schematical image of the day side magnetic reconnection due to a southward component of the IMF

A disturbance of the geomagnetical field by the influence of the varying IMF causes reconnection as a short-term effect but usually also causes a long-term effect called magnetic substorms. The field lines reconnected on the day side flip over to the tail and get closed by a second reconnection process. While the day side magnetic field decays the night side magnetic field increases and the magnetotail extends. The extended lobes reconnect in the middle of the tail to build a more stable and hence more dipolar field. This again pushes plasma towards Earth on the sunward side and pushes plasma away from the Earth on the other side of the reconnection point. The earthward accelerated plasma could flow down the field lines to the auroral zones and enforces the ring current as well.

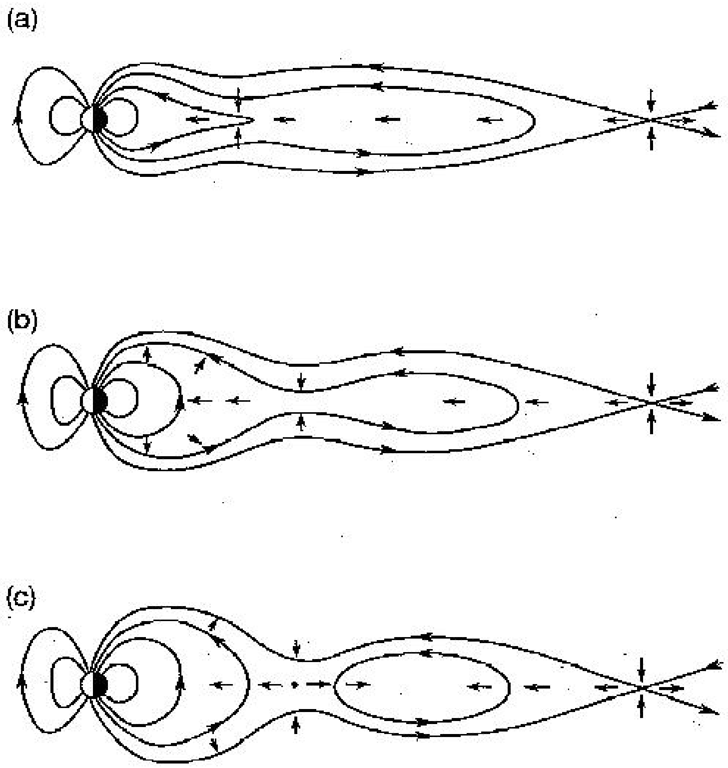

Figure 3: the characteristics of a magnetic substorm: a) the growth phase due to the backward motion of the day side field lines and the extension of the tail, b) the collapsing field lines at the middle of the tail, c) tailward and earthward plasma flow induced by the reconnection process

The increasing ring current is the main reason for civilising damages because it induces a variation of the magnetic field and on the surface of Earth which again creates an electric field. This electic field causes voltage differences at the Earth's surface which could lead to enormous currents between two points connected by a conducting cable like a power line. These currents are called geomagnetically induced currents.

The loss of plasma in the magnetosphere due to the different processes of a magnetic storm is compensated by plasma from the ionosphere and from the solar wind.
All the variations in the IMF are related to the activity of the sun that varies on a long time scale in a eleven year cycle. But there are other short-term variations as well.

Figure 4: the aurora as one effect of a geomagnetic storm

4 Magnetic storms an their effects on our civilisation

Especially for our high-tech, civilised society magnetic storms can provoke huge damages as it happened several times in the past.
As mentioned obove between all kinds of electroconductive connected grounding points could geomagnetically induced currents can be formed which could destroy the according cabels, pipelines, transformers and so on.
Another problem is the expansion of the upper atmosphere due to plasma heating which risks to demage Earth near orbiting satellites because of the rough contact with this layer.
For aircrafts and astronauts radiation of high energy particles is a problem for electronics and health.
Also communication systems using the ionosphere for radio signal reflection over long distances is disturbed by the fluctuations in the ionosphere.

All these effects related to the complex processes of a magnetic storm which means a stronger solar wind due to the activity of the sun can be reduced in their caused damage by a prediction of space weather. These predictions are nowadays possible because of the intensive observations of the sun's activity and Eath's magnetic field by satellites and ground based stations and the roughly understood developement of the interactions.

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