Introduction to Space Weather, Solar Cycle and Solar Activity

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Community Coordinated Modeling Center

NASA Space Weather Center

What is Space Weather?

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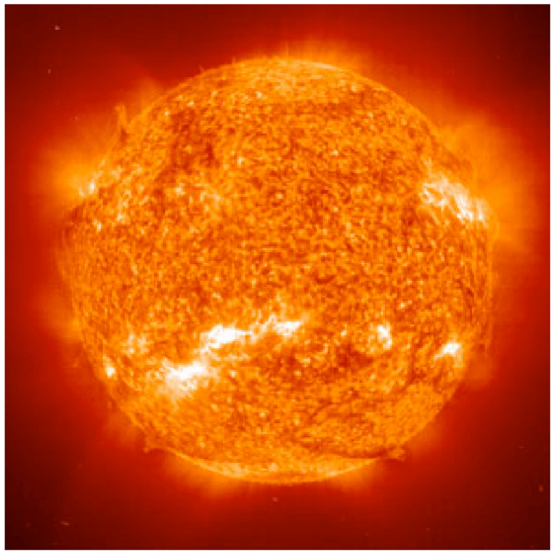
What is Space Weather?

"**Space Weather** refers to conditions on the **Sun** and in the space environment that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."

National Space Weather Program Web site:
www.nswp.gov

Space Weather Driver



Sun as seen with 30.4 nm UV spectral line of the EM spectrum.

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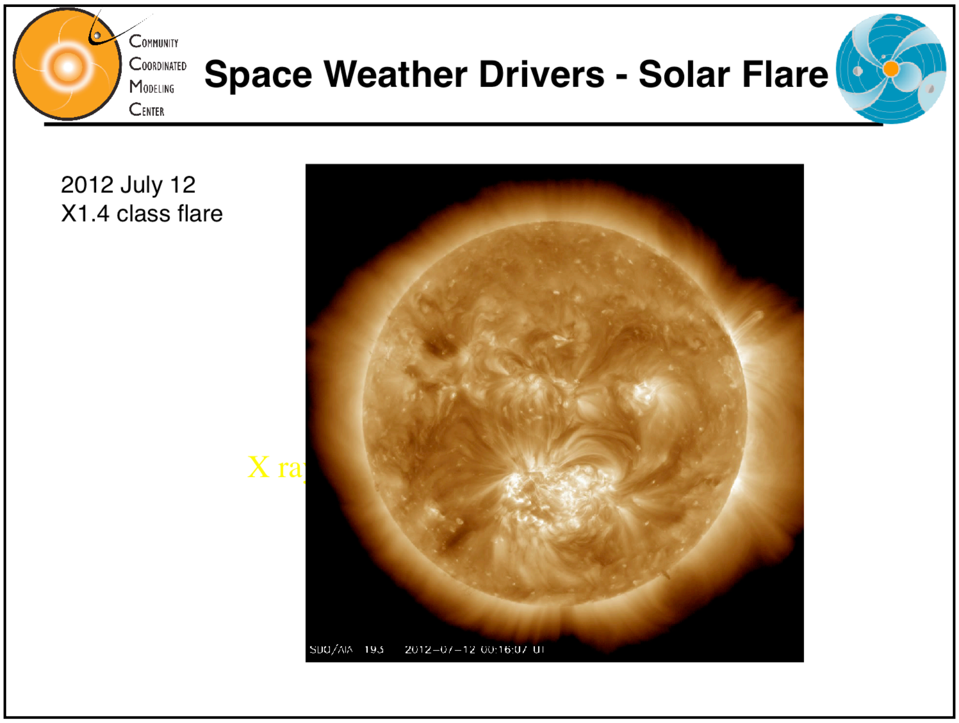
Space Weather Drivers – Solar Wind

Solar Wind – plasma constantly blowing from the Sun, reaches the Earth in 4-5 days



Another solar phenomenon important to the space weather is solar flare, a sudden brightening observed over the Sun's surface or the solar limb, which is interpreted as a large energy release. Flares are mainly followed by a mass ejections from the solar atmosphere called coronal mass ejections (next slide). The flare ejects clouds of electrons, ions, and atoms through the corona of the sun into space.

In this slide is shown the solar flare of 2012 July 12.

In the upper panel is shown GOES satellite time line for the X-ray intensity (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/GOES_X-RAY) in two different wave length intervals . A strong flare usually manifests itself by a sudden a jump of the X-ray intensity.

The lower panel shows SDO satellite (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary) images of the same flare in three different wave length intervals: 1) the left is SDO EVE X-ray image (***http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Full_iSWA_Cygnet_List***

The central panel shows SDO AIA extreme ultraviolet image for 19.3 nm http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/SDO_AIA_193 and the right panel - for a shorter wave length of 13.1 nm

http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/SDO_AIA_131

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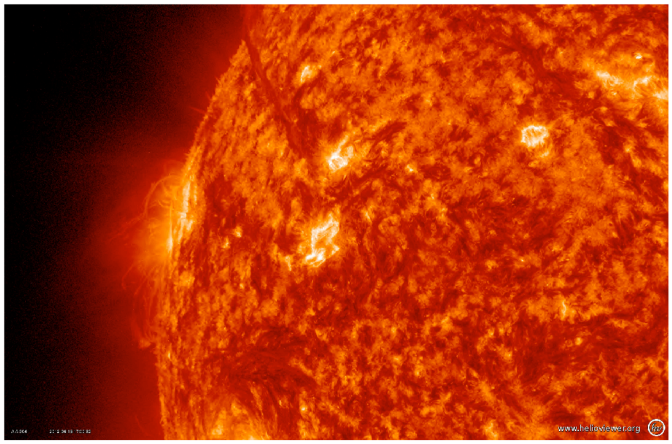
Space Weather Drivers - CME

Coronal Mass Ejection – Reaches the Earth in 1-6 days



Energetic Particles Accelerated by Solar Flares and CMEs

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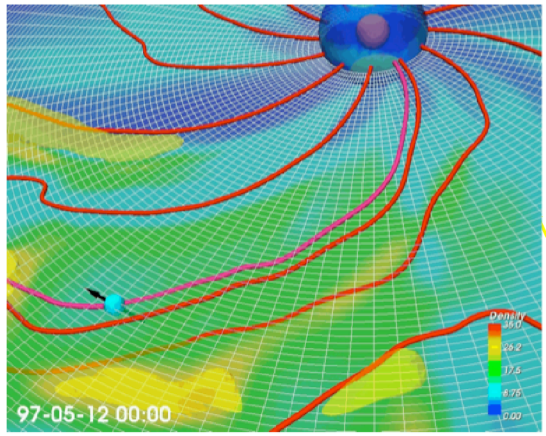
Sun Is a Giant Magnet! The interplanetary space is permeated with it's magnetic field

Charged particles move along the interplanetary magnetic field lines and can reach planet or satellite if the active region is properly connected

X ray



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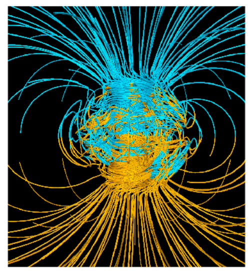
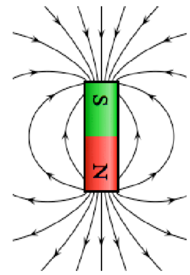
The Role of the Magnetic Field

Earth Is a Giant Magnet too!

William Gilbert (1544 – 1603)

Close to it's center the magnetic field looks like a magnetic dipole





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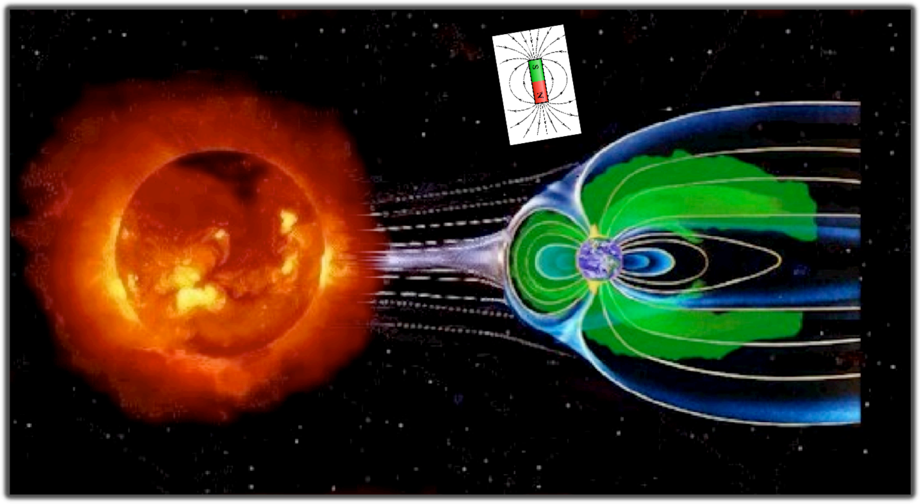
Earth's Magnetic Field – Our Shield



Space Weather Impacts

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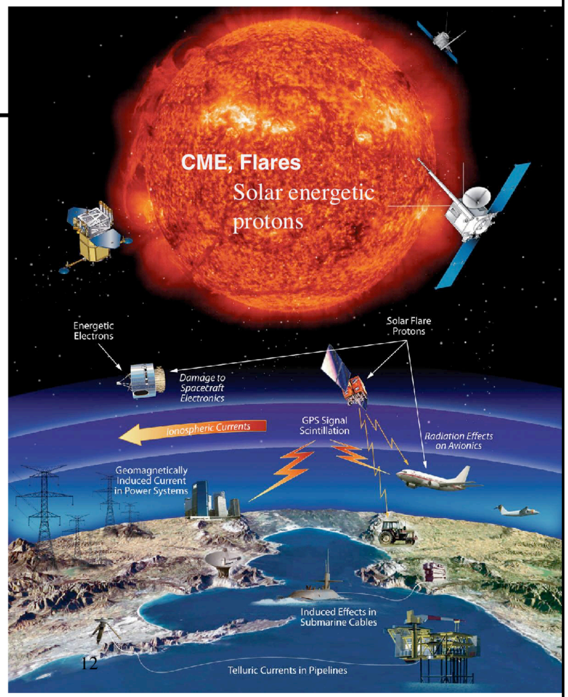
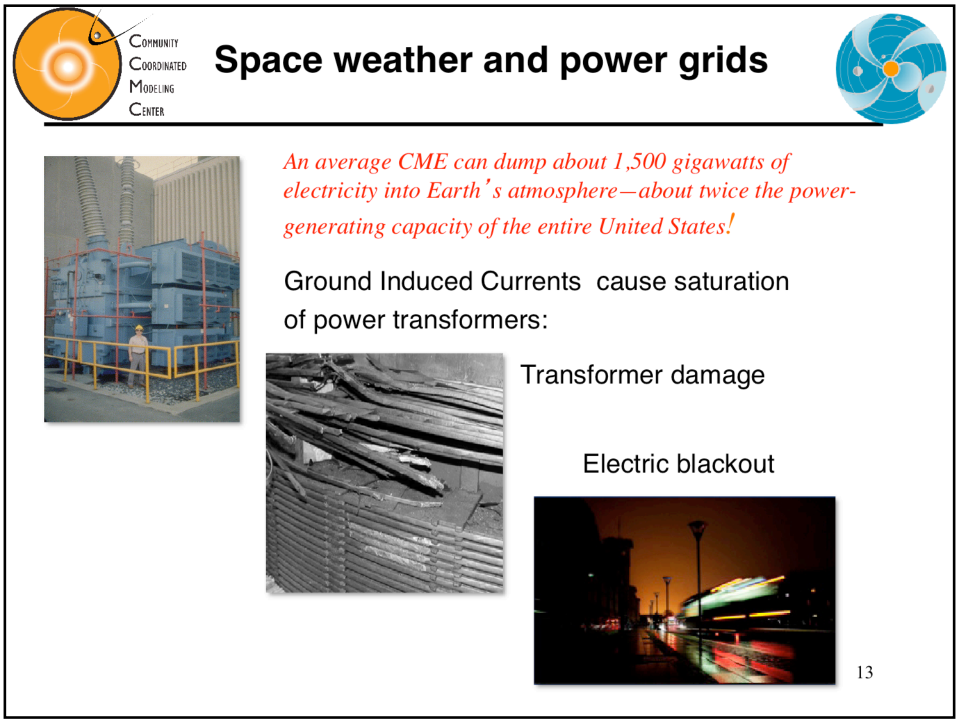
Space Weather Impacts

- Cause radio blackout through changing the structures/composition of the ionosphere emissions
  lasting min to hours
- Affect radio comm., GPS, directly by its radio noises
- Contribute to SEP – proton radiation
  lasting a couple of days
- Affect spacecraft electronics
- Power grid, pipelines



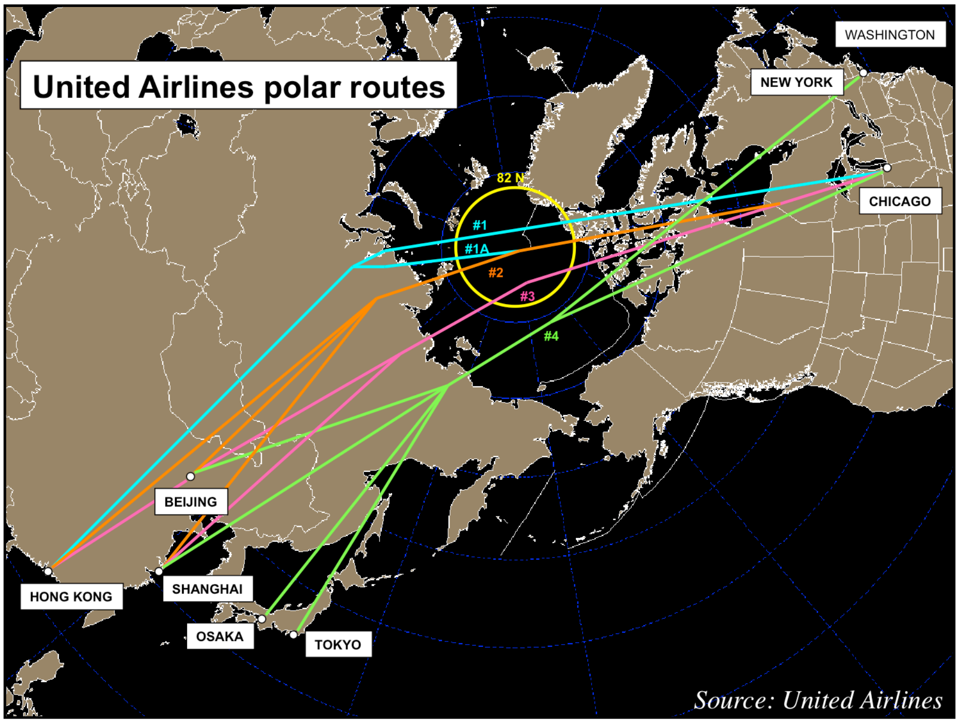


- Power transformer from Lethabo, South Africa. Severe winding damage due to GIC on October-November 2003.

- Malmo blackout: October 30, 2003. 50000 customers without electricity for about an hour. Estimated losses 500.000 USD.

- Quebec blackout: March 13, 1989. 6 million people without electricity for about a 9 hours. Estimated Quebec losses 13.000.000 USD.

- NRC report from 2008 and NERC/DoE report from 2010.



80 degree north requires HF comm rather than satcomm

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Sun and Its Activity

In this presentation I will be talking about the Sun and its activity in relations to the space weather

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary/_space_weather)

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Structure of the Sun

Core (up to ~ 0.25 Rs): T ~15 MK and very dense. Nuclear fusion.

Radiation Zone (0.25 – 0.7Rs): transparent for photons. T ~ 7 – 2 MK

Convective zone: (0.7 – 1.0 Rs): T is lower. Energy is transported outward mostly by *convection*.

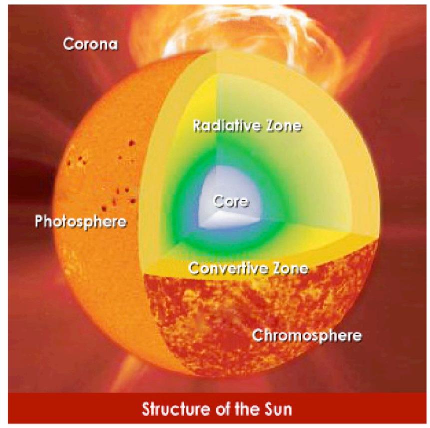
Photosphere (surface): 6000 K
- Sunspot (typical) 4200 K

(~100 km thick).

Chromosphere: 20,000K (1.0Rs-2000km)

Transition region: 20000K – 1-2 MK (above 2000 km ~ 100 000 km, no clear range)

Corona: 2 MK



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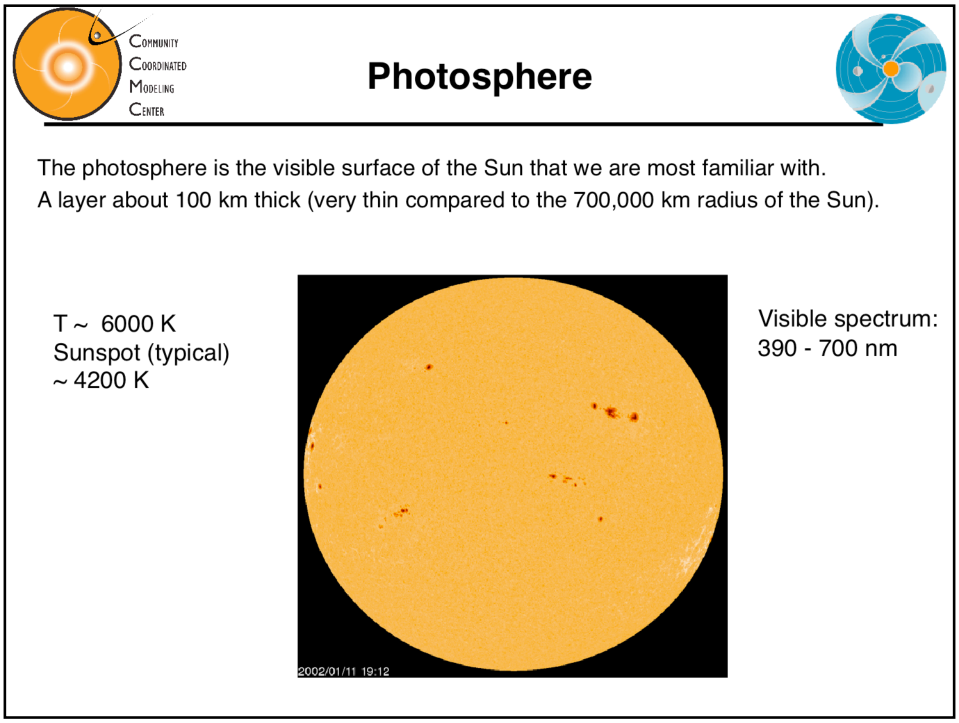
Let's go back to the Sun. In this picture schematically is shown the structure of the Sun and it's regions. 1) In the center there is very hot and dense solar core (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary)

where all the solar energy is created. The energy equivalent to billions of hydrogen bomb explosions is released each second. 2) Above the core there is a cooler and less dense radiation zone (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary)

which is transparent for photons. 3) Higher up is the convective zone (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary), where energy is transported by circular motion of the heated material. 4) Above the convective zone is coolest (~ 6000 K only) solar region called photosphere (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary) - or solar "surface".

5-6) Above the photosphere is hotter chromosphere (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary) and above the chromosphere, more hot transition region (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary).

7) The outer part of the solar atmosphere is called solar corona. The temperature reaches millions of Kelvin there. Scientists are still debating what mechanisms heat the corona.



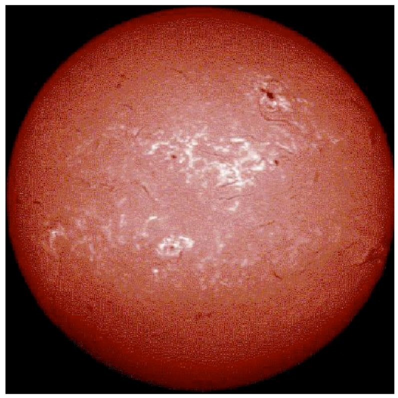
The photosphere is the visible surface of the Sun that we are most familiar with. A layer about 100 km thick (very thin compared to the 700,000 km radius of the Sun). The temperature is about 6000 degrees and in relatively darker sunspots about 4000 K.

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary/photosphere)

Chromosphere

Above the photosphere ~ 2000 km thick. The temperature rises to ~ 20,000°. Hydrogen emits light that gives off a reddish color which can be seen in prominences that project above the limb of the sun during total solar eclipses.

T ~ 20 000 K



656.3 nm

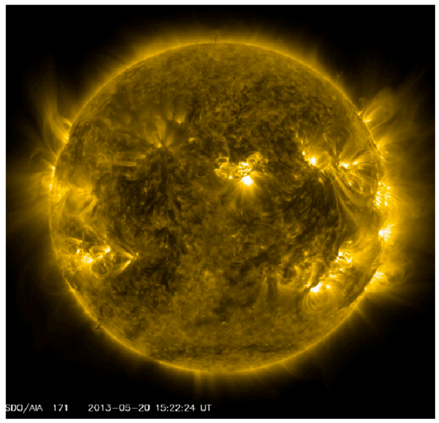
Chromosphere is an irregular layer above the photosphere ~ 2000 km deep. The temperature rises to ~ 20,000°. Hydrogen emits light that gives off a reddish color (H-alpha emission) which can be seen in prominences that project above the limb of the sun during total solar eclipses. The chromosphere is also the site of changes in solar flares, prominence and filament eruptions, flow of material in post-flare loops.

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary/_chromosphere)

Transition Region

The temperature rises to from 20000 to ~ 1-2 MK. Below, gravity dominates the shape of most features, so that the Sun may be described in terms of layers and horizontal features (like sunspots); above - dynamic forces dominate the shape of most features, so that the transition region itself is not a well-defined layer at a particular altitude.

T ~ 20 000 K to ~ 1-2 MK



17.1 nm

Above the chromosphere there is a transition region. The temperature from 20000 to ~ 1-2 MK. Below, gravity dominates the shape of most features, so that the Sun may be described in terms of layers and horizontal features (like sunspots); above, dynamic forces dominate the shape of most features, so that the transition region itself is not a well-defined layer at a particular altitude.

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary)

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Corona

The Corona is the Sun's outer atmosphere. It is visible during total eclipses of the Sun as a pearly white crown surrounding the Sun.

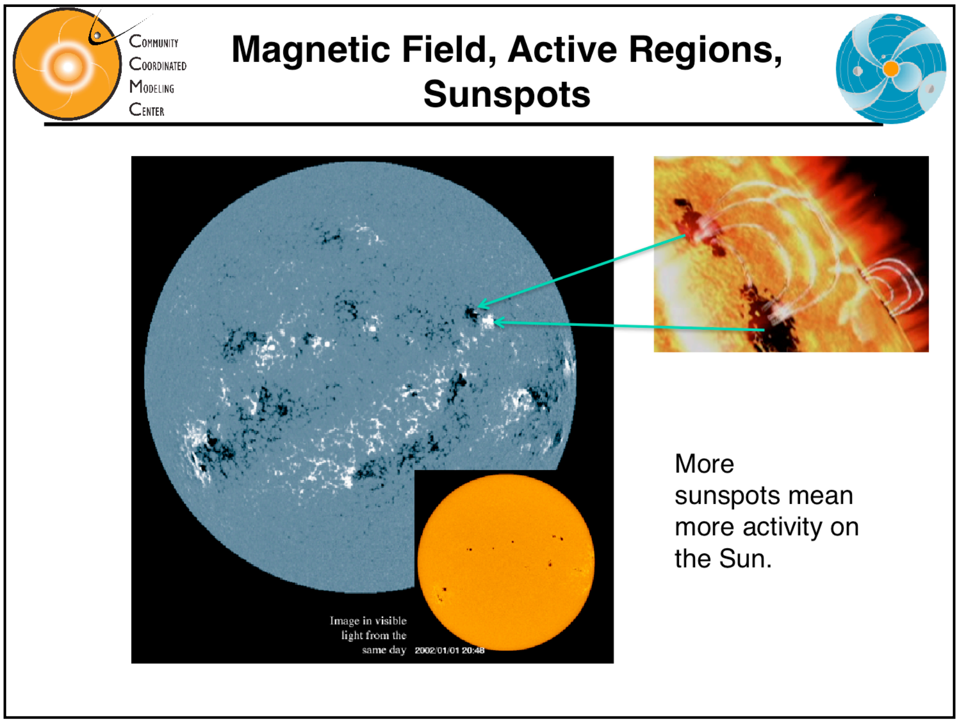
T ~ 2 MK

The heating of corona is an ongoing research area

The Corona is the Sun's outer atmosphere. It is visible during total eclipses of the Sun as a pearly white crown surrounding the Sun. The temperature is about 2 million K.

The heating of corona is an ongoing research area

http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary/_solar_corona



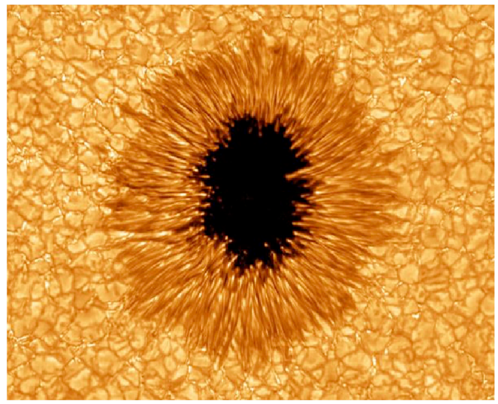
As I mentioned earlier, solar magnetic field plays a crucial role in the processes on the Sun and solar activity. In this slide is shown a magnetogram (

http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary) - magnetic field map - of the solar photosphere. The black and white spots describe the concentration of relatively strong magnetic field with different polarity for each color. This is called an active region. Most of the flares and CMEs originate from active regions. In the right upper corner is an artists depiction of a part of photosphere and solar atmosphere for an active region (

http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary). In this depiction two sunspots have opposite magnetic polarity, connected to each other with magnetic field loops. At the photospheric level strong magnetic field of a sunspot prevents particles from being heated easily, so the temperature of the sunspot is lower than the temperature of ambient material. Hence the name "sunspot", which looks darker in the visible part of the spectrum. See the insertion of the solar disc image in the visible light for the same day as the magnetogram.

Sunspot Close Up

Sunspots are caused by intense magnetic field inhibiting convection and leaving their temperature (~ 3000–4500 K) lower than the temperature of surrounding material (~ 6000) K. This makes them visible as dark spots. Size varies from 16 km to 160,000 km in diameter. Most solar flares and CMEs originate in magnetically active regions around sunspot groups.



Here is a close look to a sunspot (http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary.

) given by HINODE satellite.

As I said earlier, sunspots are caused by intense magnetic field, which inhibits convection, leaving their temperature (~ 3000–4500 K) lower than the temperature of surrounding material (~ 6000) K and makes them visible as dark spots. Sunspot sizes vary from 16 km to 160,000 km in diameter. Sunspots host coronal loops

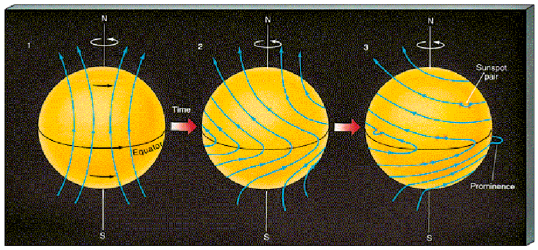
(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary)

and magnetic reconnection events

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary).

Most solar flares and CMEs originate in magnetically active regions around sunspot groups.

Solar Magnetic Field



-The Sun is permeated by global roughly dipole magnetic field;
-The field is produced by a circular electric current flowing deep within the Sun;
-The current is produced by shear (stretching of material) between different parts of the Sun that rotate at different rates, and the fact that the Sun itself is a very good electrical conductor;
- The field, as plasma moves, changes constantly due to plasma motion

What is the mechanism that creates solar magnetic field?.

The overall picture is the following:

-The Sun is permeated by overall roughly dipole magnetic field, similar to the Earth.

-The dipole field is produced by a circular electric current flowing deep within the star.

-The current is produced by shear (stretching of material) between different parts of the Sun that rotate at different rates, and the fact that the Sun itself is a very good electrical conductor.

Those are the basic principles everybody agrees on. Then, there are different theories and models that describe solar magnetic field, but similar to coronal heating problem, this is still ongoing research area.

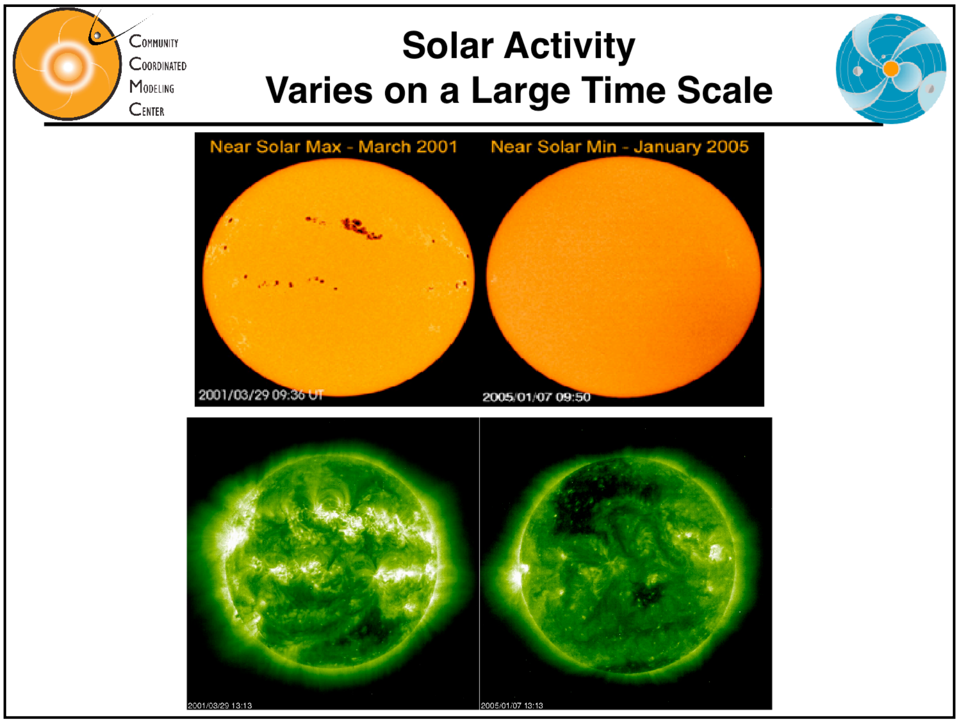
Solar Activity is Related to Magnetic field

- Magnetic field is believed to be generated at the base of the convective zone
- Fields are stressed and pushed to surface, leading to flares and eruptions.

It is believed that solar magnetic field, while changing its configuration in a constantly varying solar atmosphere, releases energy, accelerating solar plasma and causing flares and CMEs.

What is known for sure, is that solar activity is related to its magnetic field. It is believed that when the magnetic field changes its configuration in a constantly varying solar atmosphere, this leads to release of energy and accelerating of solar plasma, causing flares and CMEs.

Solar magnetic field is believed to be generated at the base of the Convective zone. Fields are stressed and pushed to surface.



So, more sunspots, or more regions of concentrated strong magnetic field are on the solar surface, more active is the sun in producing flares and CMEs. Solar activity varies on a large time scale. This slide shows variation of the solar magnetic field and related solar activity in time.

Left row – near solar activity maximum (March, 2001), right row – near solar activity minimum (January, 2005). The upper panel shows the photosphere in visible part of the spectrum, the lower – solar atmosphere in ultraviolet wavelength 19.5 nm.

You can see a number of sunspots in photosphere and corresponding bright areas in the solar atmosphere during the solar maximum, and almost spotless photosphere and much darker atmosphere during the solar minimum.

Statistics shows that during the solar activity maximum for example there are about 5 CMEs per day, and during the solar minimum few CMEs a week (the ratio is of the order of 10).

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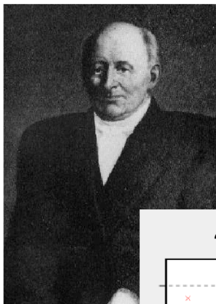
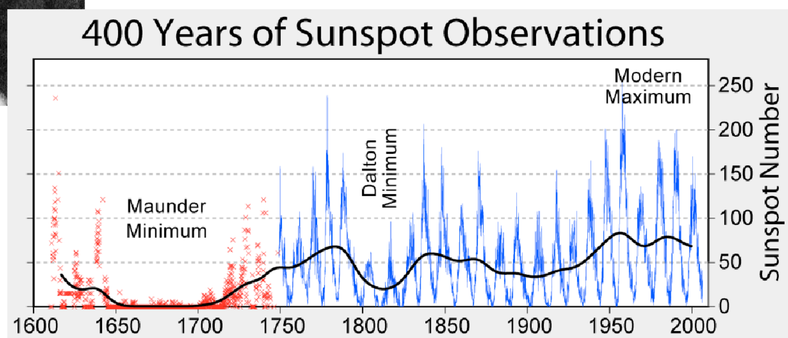
Solar Cycles



Samuel Heinrich Schwabe (1789 – 1875)

High and low sunspot activity repeats about every 11 years



German pharmacist Samuel Shcwabe, observing Sun as an amateur astronomer in the 19 century, discovered accidentally solar cycles

(http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary/solar_cycle_of_magnetic_activity)

He was recording sunspots each day and after almost 20 years of observations discovered that high and low sunspot number repeats about every 11 years.

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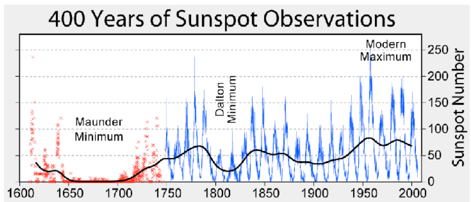
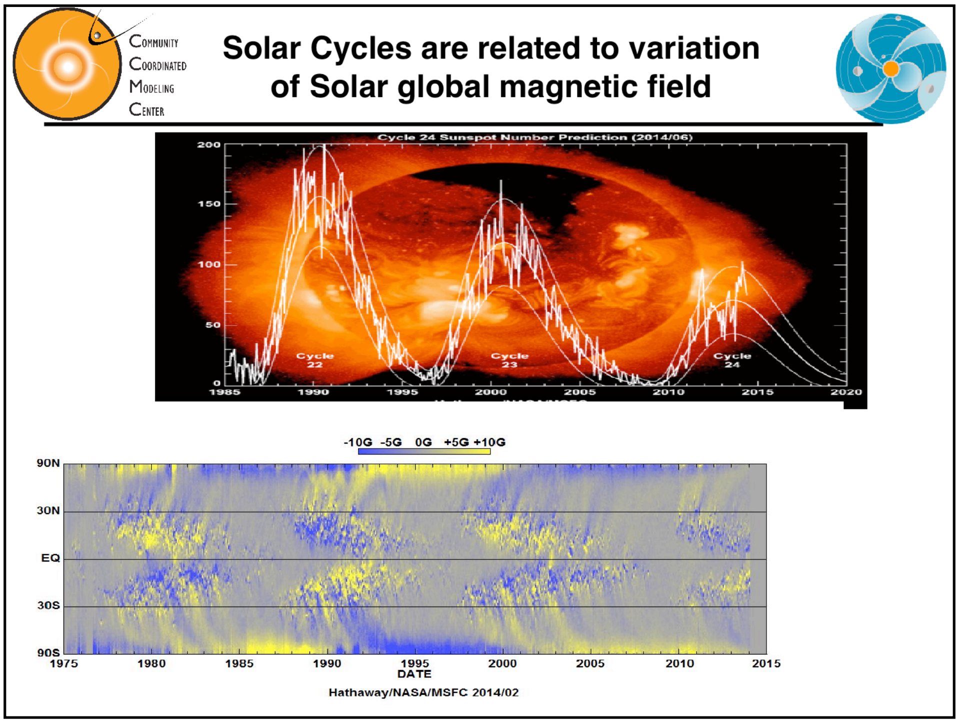
Little Ice Age



Pieter Brueghel the Elder

Hendrick Avercamp

Variability of the Solar activity affects the climate variation, but on time scale much larger then the regular weather variation time scale. During and later the Maunder Minimum it was very cold in Europe and this is reflected in the works of great Dutch and Flemish painters.



Scientists know now that the solar rotation results into a solar magnetic field variation cycle with the period of about 22 years. The inversion of solar global poloidal (meridianal) field component happens every 11 years at the moment of maximum activity. The scenario of the solar cycle is the following:

Solar minimum occurs when the magnetic field is concentrated in the polar regions with a certain polarity of the global poloidal magnetic field component. At this time there are very few sunspots on the solar disk.

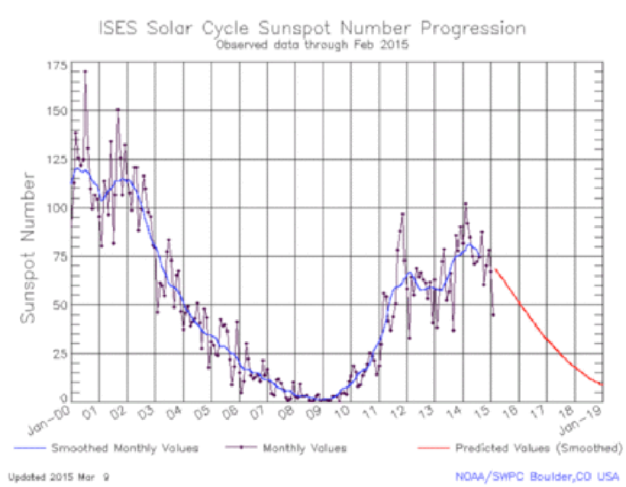
Then, over the coarse of the time, the number of sunspots increases and they are traveling towards the equatorial regions. There number reaches maximum in about 5.5 years.

Over the coarse of the next ~ 5.5 years, the magnetic field gradually becomes larger at the polar regions again, but with the different polarity of the global poloidal field component. At the end of the 11 year cycle, the number of sunspots is very low again.

Then the cycle repeats itself and the initial poloidal field direction becomes the same as ~ 22 years ago.

Current Solar Cycle 24

4-th slowest growth from the minimum ever.



Could it be that we are heading towards another minimum?

The current solar cycle 24 is characterized by very slow growth starting from the minimum in 2007-2008 (4-th slowest growth ever) and relatively low activity.

Could it be that we are heading towards another minimum?

The answer is: we do not know.

We know very little about how does the solar magnetic field creation works in reality.