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# Solar activity and its effects on the ionosphere and VLF array

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- The Sun, like other stars, is a huge spherical object made of hydrogen and helium. Its diameter reaches 1.400.000 km, or 109 times the Earth's diameter

Image credit: NASA

# Consider the following facts about the Sun:

1. **Sunspots** are cooler than the surrounding photosphere. WHY?
2. **Granules** have typical lifetimes of about 10 minutes
3. Solar **prominences** are arcs of ionized gas.
4. **Solar flares** emit bursts of X rays and affect on the ionosphere
5. **Coronal Mass Ejections** (CMEs) cause aurorae, disrupt power grids, interfere comunications

Image taken by Yohkoh sattlite

# Structure of the Sun

The Sun is divided into two parts: the interior and the atmosphere.

# The Photosphere

The thickness of the photosphere layer is ~ 500 km. The temperature at the bottom of the photosphere is 6600 K and temperature at the top of the photosphere is 4400 K.

Average temperature ?

On the photosphere, there are remarkable features such as sunspots, granules and solar flares.

The lifetime of an individual granule is only 5 to 10 minutes

The image shows an irregular-shaped sunspot and granules on the Sun's surface, seen with the Swedish Solar Telescope on August 22, 2003. (credit: ISP/SST/Oddbjorn Engvold, Jun Elin Wiik, Luc Rouppe van der Voort)

# The Chromosphere

H-alpha image courtesy of NOAA Space Environment Center

The chromosphere is the next layer of the photosphere with a thickness of about 2000 km to 3000 km.

Temperature is about 10000K

Prominences can be seen above the limb of the Sun using telescope with H-α filter.

The explosions often occur with increased brightness, ultraviolet and X-ray radiation, called solar flares

# The Transition Region

- Thickness is a few kilometers
- Temperature increases sharply from 10000 K to millions K in the corona

# The corona

- The corona has a length of 50.000 to 100.000 km, and temperature of 40.000 K- 1.000.000 K
- When elipses occur, we can see the corona

***The corona are taken by  EUV and continuum wavelength from the Solar and Heliospheric Observatory (SOHO)***

# The Sun’s activity

- Solar activity is the transformation of its electromagnetic field
- The Sun’s activity: **Sunspots, Prominences, Solar flares, CMEs**
- As the frequency of sunspots increases, charged particle flows are emitted strongly from the Sun, impacting the Earth's atmosphere,

# Sunspots

*The photosphere plus sunspots (credit: by NASA/SDO)*

- The spots have a darker center are called the umbra and a lighter edge called the penumbra.
- The temperature at the sunspot is lower than the temperature around it
- Regions with strong magnetic fields.
- The sunspots are usually about 10.000 km in diameter

# Sunspots

- Charged particles spiral along magnetic field lines.

- The field lines at sunspots are closer together where the field is stronger.
- The solar plasma including ions and electrons cannot easily move perpendicular to the field lines.
- Strong magnetic fields prevent the inflow of hot plasma to replace plasma that has been sitting on the surface, radiating to space, and cooling down

# Prominences

ow (0,1nm)

The Egyptian God Ra

- Prominences are graceful loops of hot plasma
- originate near sunspots
- Heights of some loops are more than 1 million kilometers above the photosphere
- Prominences can be seen when elipses occur
- When we view against the photosphere, prominences appear as dark snake like objects, called *filament*

# Solar flares

- Solar flares are defined as a sudden, rapid, and intense change in the luminosity of the chromosphere or corona.
- Solar flares occur when the magnetic energy in the Sun's atmosphere suddenly increases.
- Radiation is emitted  from radio waves to gamma rays

# Solar flares

- The transformation of magnetic energy begins at the neutral point above the two sunspot groups.
- The magnetic field lines break and reconnect
- Some protons move faster and cause the solar proton event at the Earth's poles causing the absorption of radio waves and affecting communication…
- Electrons move to chromosphere and are blocked at the chromosphere and hard X-rays are produced by the bremsstrahlung radiation.
- On the chromosphere, the hydrogen atom is ionized by collision with an electron and radiates out the Hα spectral line (656.3 nm). In the igneous region, the corona is heated and radiates soft X-rays and UV

Soft X-ray image of a long-durational-event flare observed by *Yohkoh*.

# Solar flares

| Classification | Intensity I ( $W / m^2$ ) |
|---|---|
| B | $I \leq 10^{-6}$ |
| C | $10^{-6} \leq I \leq 10^{-5}$ |
| M | $10^{-5} \leq I \leq .10^{-4}$ |
| X | $10^{-4} \leq I$ |

Relationship between the number of solar flares and the sunspot number presented by the following formula:

$N = \alpha(R - 10)$

Where,

N: number of solar flares.

R: number of sunspots.

α: 1.5 - 2

# Coronal mass ejections

- It may occur that the twisted magnetic field holding up a prominence becomes unstable and rises up very suddenly and quickly.
- If that occurs, the material of the prominence could be released out of the Sun, reaching a speed of 1000 km/s.
- They sometimes happen at the same time as flares, but where the flare releases light, a coronal mass ejection releases material.

# Coronal mass ejections

- The reconnection taking place at various points of the magnetic field lines emerging from the chromosphere.
- After reconnection, there is a torsion magnetic field line, the base of which is located in the chromosphere.
- Charged particles are trapped, moving back and forth at the reflection points and forming an arc-shaped tube. It expands and can reach the Earth and interact with the Earth's magnetosphere
- Energetic particles high in Earth’s atmosphere cause aurorae. Solar storms damage satellites, disrupt electrical systems, interfere with communications

# Coronal mass ejections

# Solar Cycle

- The number of sunspots varies in a cycle with an average period of 11 years
- At the start of a sunspot cycle the number of sunspots is at a minimum and most of them are at around 35° from the equator. At solar maximum when the sunspot number peaks about 5.5 years later, most of the sunspots are within just 5° of the equator.
- It is currently in cycle 25 which began in December 2019

# Solar flares cause the disturbances of the Earth’s ionosphere

# The Earth's ionosphere

- The Earth's ionosphere is the top part of the atmosphere with an altitude of 60 km to 1500 km. Energy in the solar radiation ionizes gas molecules such as $N_2$, $O_2$, and O into positive ions and free electrons.
- The free electrons generated during this process can greatly affect the transmission of radio signals. The ionosphere is divided into different layers including D, E and F

(Deborah Scherrer, 2007)

# Solar flares effects on the ionsphere

*Image courtesy of Morris Cohen, Stanford University*

- When the solar flares occur, the strong ionizing radiation causes the electron density of the D layer to dramatically increase with 1-2 orders of magnitude
- Very Low Frequency (VLF) signals (3 kHz – 30 kHz) propagate in the Earth - Ionosphere waveguide

# VLF array

- VLF array: SuperSID receivers are installed around the world
- They can observe the effects of sunrise and sunset phenomena and solar flares on the Earth's ionosphere via monitoring the VLF signals propagating from many transmitters to a receiver site
- Education

# Solar flares effects on the ionsphere

- Enhancements of electron density cause the sudden changes of VLF amplitude

(Scherrer, 2007)

# VLF array

English Español
About SID DATA Linking to this Page

- ○ Superimposed
- ◉ Vertical

- ☐ Don't Display Monitor Sunrise and Sunsets (Colored Arrows)
- ☐ Don't Display Station Sunrise and Sunsets (Black Arrows)

- ☐ Don't Display Solar Flares (From GOES)

(C1.0) Visible Minimum Flare Strength

- ☐ Show estimated data quality (lower is better)

Download Data Files

Update Graph

**View Data by Date**
**Experimental Event Search**
**Map of Monitors**

**View Data by Monitor**
**Clear Monitor Selection**
Selected Monitors:

**Graph Length:**
- ○ 1 Hour
- ○ 6 Hours
- ◉ 1 Day
- ○ 3 Days

**Graph Size:**
- ◉ Small
- ○ Medium
- ○ Large

Activate Windows
Go to PC settings to activate Windows.

# VLF array

Flares can be trach back to the solar active region that produced them

| #Event | Begin | Max | End | Obs | Q | Type | Loc/Frq | Particulars | | Reg# |
|---|---|---|---|---|---|---|---|---|---|---|
| 5580 | 0003 | 0014 | 0020 | HOL | 3 | FLA | N21W37 | SF | | 3376 |
| 5540 + | 0004 | 0021 | 0036 | G16 | 5 | XRA | 1-8A | C8.4 | 1.1E-02 | 3379 |
| 5540 + | 0008 | //// | 0948 | LEA | C | RSP | 132-180 | CTM/1 | | 3379 |
| 5540 + | 0010 | 0016 | A0023 | HOL | 3 | FLA | N16E24 | 2N | ERU | 3379 |
| 5550 | 0110 | 0110 | 0114 | LEA | 3 | FLA | N22W38 | SF | | 3376 |
| 5560 | 0117 | 0121 | 0126 | LEA | 3 | FLA | N22W38 | SF | | 3376 |

# Summary

- Solar activity includes sunspots, solar prominences, solar flares, and coronal mass ejections (CMEs).
- Flares and CMEs affect on the Earth’s ionosphere and magnetosphere.
- VLF array for observing the effects of solar flares on the Earth’s ionosphere

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# Thank you for your attention!