Role of the Ionosphere & SPWx in Military Communications

Solar-Terrestrial
Centre of Excellence


LARGE SCALE PICTURE OF SPHERES
Around the Earth
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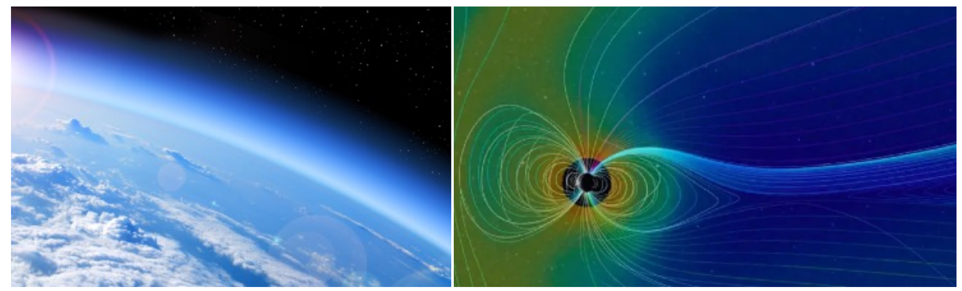
Space Weather

The Sun’s energy impacting earth’s atmosphere and magnetic shield.



As we go out into space, the atmosphere becomes very thin, until by the time we are in space, it has almost vanished. Almost, but not quite. Even in space there are some atoms which are often moving very quickly. Many forms of energy also move through **space** and it is the **interaction of energy and atoms that produces what we refer to as space weather**. In particular, space weather is the changes that occur in the space environment.

The **sun** is the source of 'normal' terrestrial weather. It is also the **primary (but not the only) source of space weather**. Most aspects of space weather affect us to some extent. The more our society becomes dependent on technology and the more we utilize space, the more we are affected by space weather. Some aspects of space weather are benevolent, and allow activities not otherwise possible such as long range radio communications. Some aspects are benign but fascinating such as the Aurora, and some are malevolent. **Like terrestrial weather, it depends on the situation and the event.**

Large scale picture of the spheres around Earth

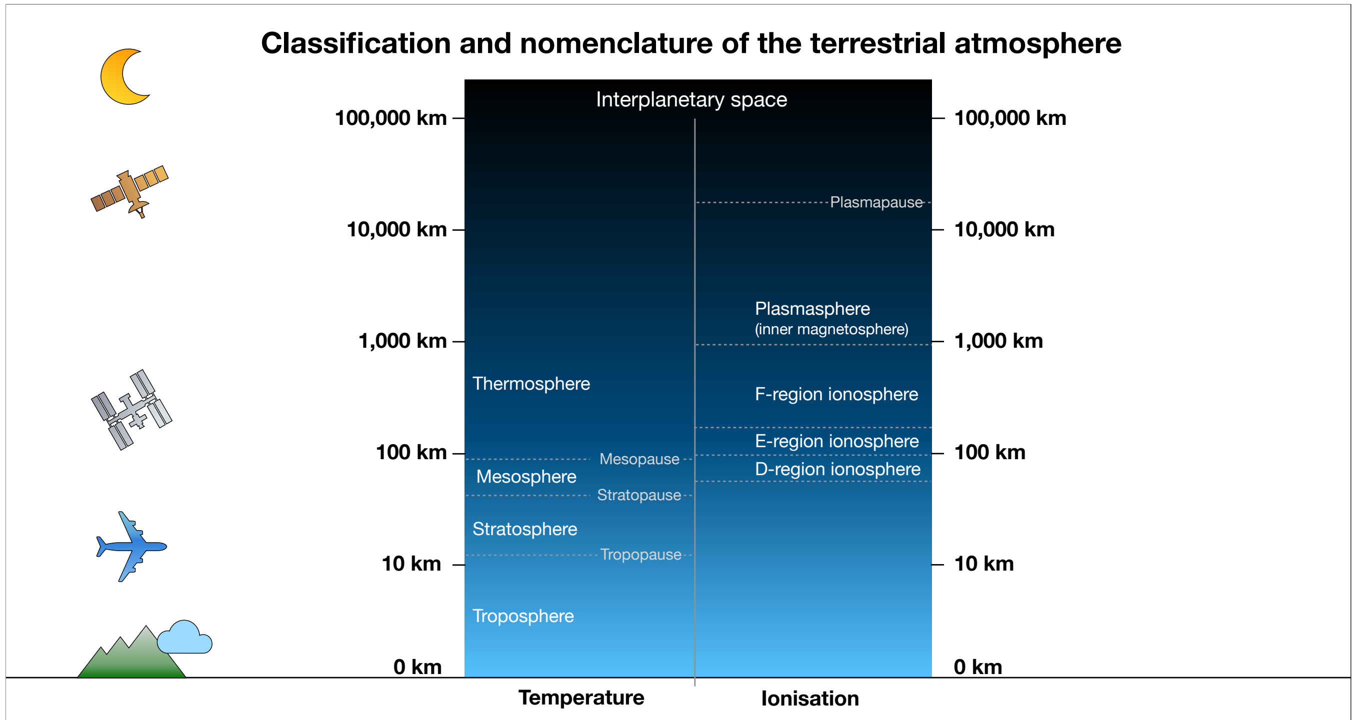
1. Earth’s neutral atmosphere: troposphere, stratosphere, mesosphere and thermosphere

2. Earth’s charged atmosphere: the ionosphere and plasmasphere

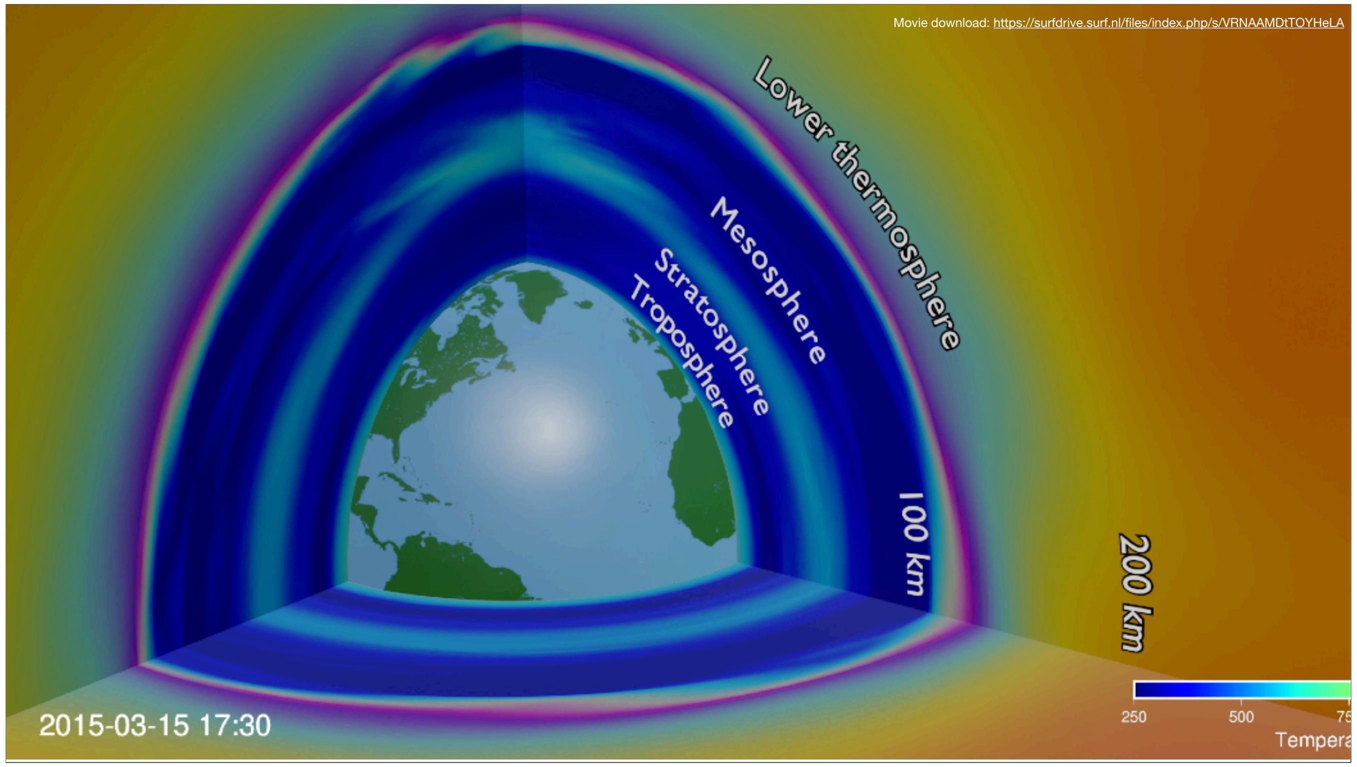
3. Magnetosphere

Where does the atmosphere end and where does space begin?

- **Biology / human activity:** it becomes very hard to survive for long in low oxygen and cold temperature environments on Earth's highest mountains [~5 km]
- **Density:** At what altitude does the density of particles become indistinguishable from that in interplanetary space?
- **Weather/climate:** "hardly anything interesting that affects our living environment happens above the stratosphere" [12 km?] (or does it?)
- **Flight:** It gets harder to generate enough lift on a wing in very thin air at higher altitudes. When does an aircraft turn into a rocket or a satellite? [~80 km]
- **Spaceflight 1:** when an orbiting object gets low enough, it experiences so much drag that it cannot complete another orbit [~100 km] and/or it generates so much frictional heating that it breaks up if unprotected [~80 km].
- **Spaceflight 2:** to what altitude can spacecraft measure/make use of aerodynamic forces? [at least 1500 km]
- **Connections between atmospheric layers:** to what altitudes can atmospheric waves, which originate at the Earth's surface, propagate? [at least 300 km]
- **Corotation:** To what altitude do particles rotate along with the Earth's rotation around its axis? [up to several 1000 km]



Based on G.W. Prölss, Physics of the Earth's Space Environment, Figure 2.13


Movie download: https://surfdrive.surf.nl/files/index.php/s/VRNAAMDtTOYHeLA
Lower thermosphere
Mesosphere
Stratosphere
Troposphere
100 km
200 km
250
500
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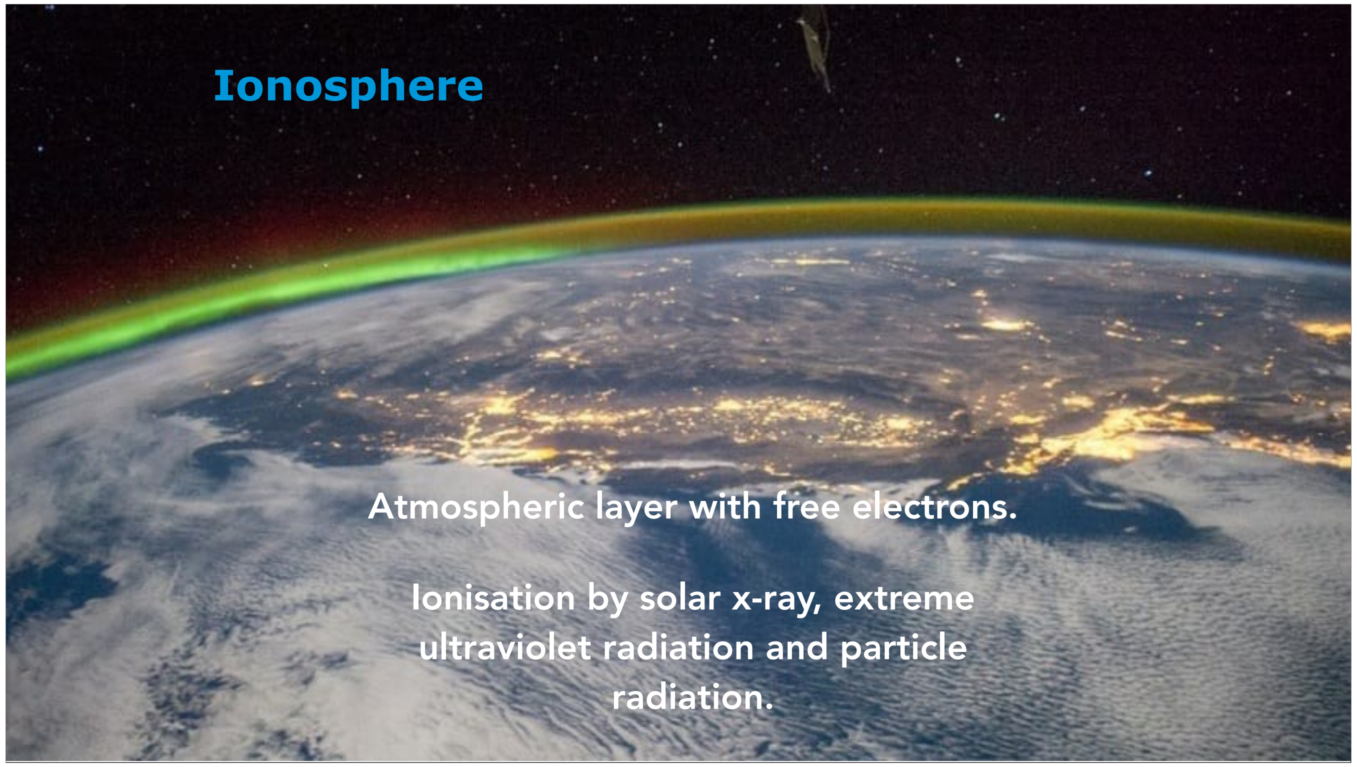


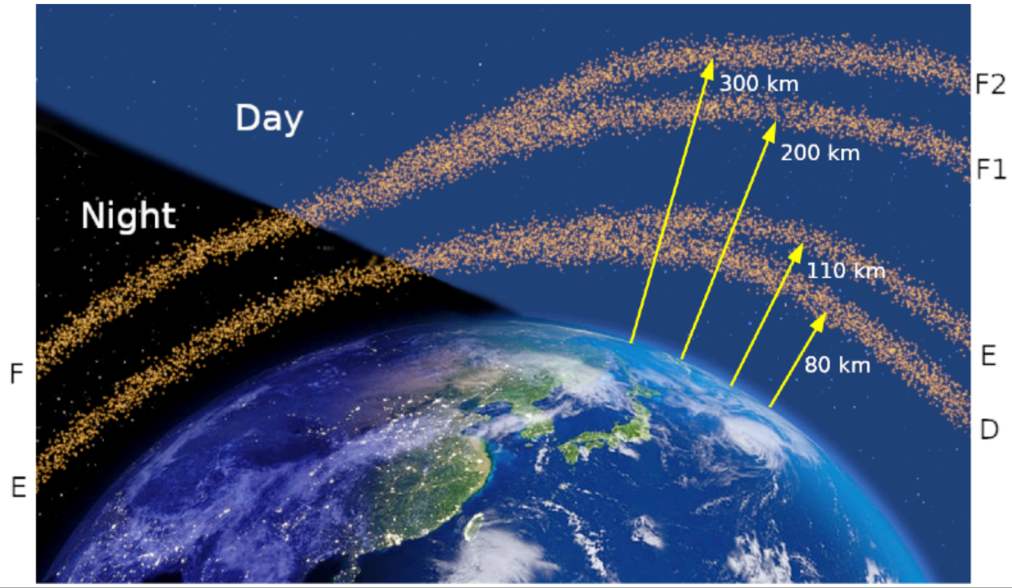
The ionosphere is that part of the upper atmosphere where free electrons occur in sufficient density to have an appreciable influence on the propagation of radio frequency electromagnetic waves. This ionization depends primarily on the Sun and its activity. ionospheric structures and peak densities in the ionosphere vary greatly with time (sunspot cycle, seasonally, and diurnally), with geographical location (polar, auroral zones, mid-latitudes, and equatorial regions), and with certain solar-related ionospheric disturbances.

The major part of the ionization is produced by solar X-ray and ultraviolet radiation and by corpuscular radiation from the Sun. The most noticeable effect is seen as the Earth rotates with respect to the Sun; ionization increases in the sunlit atmosphere and decreases on the shadowed side. Although the Sun is the largest contributor toward the ionization, cosmic rays make a small contribution. Any atmospheric disturbance affects the distribution of the ionization.

The ionosphere is a **dynamic system controlled by** many parameters including **acoustic motions of the atmosphere, electromagnetic emissions, and variations in the geomagnetic field**. Because of its extreme sensitivity to atmospheric changes, the ionosphere is a very sensitive monitor of atmospheric events.

The most accurate way of measuring the ionosphere is with a ground-based ionosonde, which records data as ionograms.

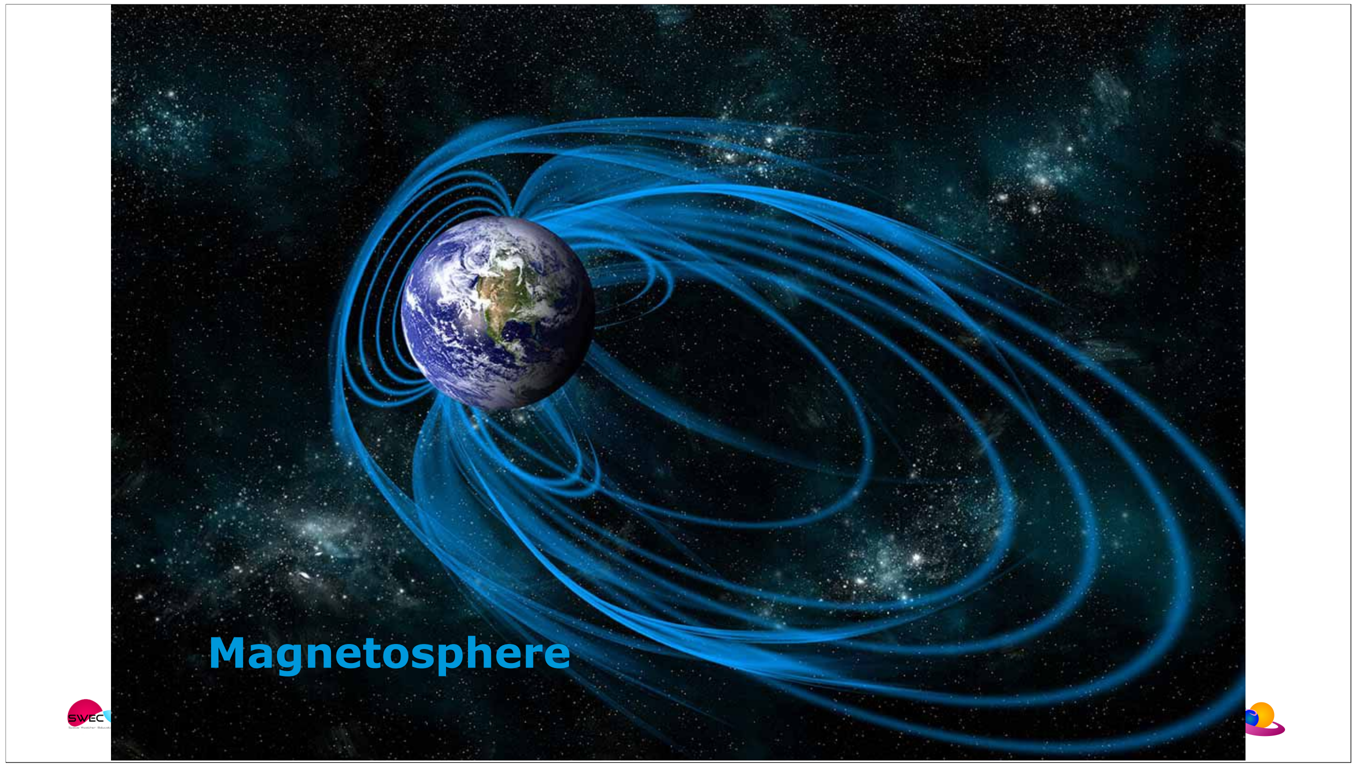
Ionosphere



http://www.nerc-bas.ac.uk/public/uasd/magneto/ionosp/intro.html

The ionosphere is a relatively thin shell around the earth between about 70 and 1000 km above the earth's surface. It is the transition region between the dense, electrically neutral atmosphere below and the very thin, ionised plasmasphere and magnetosphere above. When the plasma up above is caused to move, magnetic field lines communicate this motion down to the ionosphere as if they were pieces of string tying the different plasma regions together. However, ions cannot move so easily in the ionosphere because they must wade through a sea of neutral particles which slow them down by frequent collisions. Yet the smaller electrons manage to dodge the neutral particles and move freely. As a result of the different electron and ion motions horizontal electrical currents flow in the ionosphere which cause magnetic perturbations on the ground. The motions can also help generate waves in the ionosphere that move with the electrons and can be detected by radars.

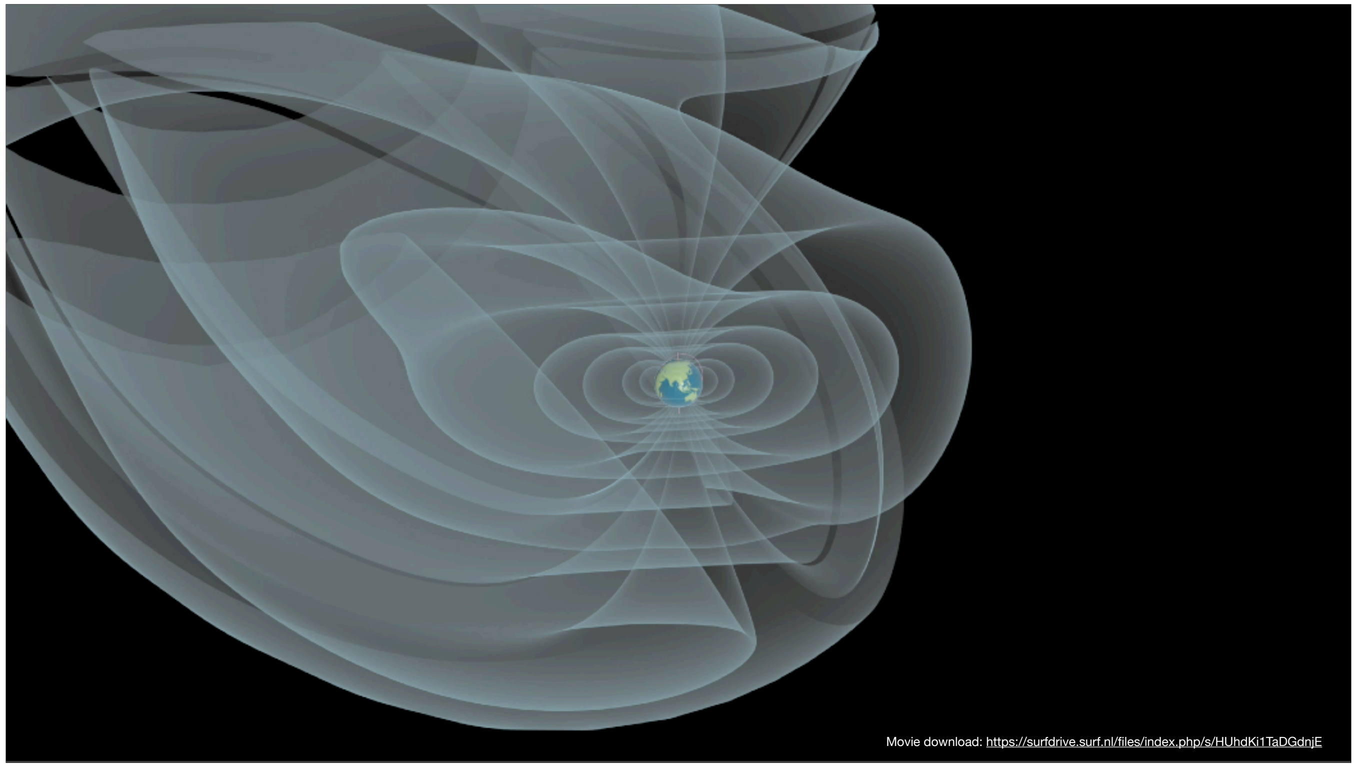
The ionosphere acts as both a help and hindrance to long distance radio communication. The ionosphere helps by reflecting high frequency (HF) radio waves around the globe. It hinders by slowing down and absorbing all radio waves. The effects are very small on very- and ultra-high frequency (VHF and UHF) radio waves, but they can be important where radio waves from satellites are used for precise global positioning. The effects can be more severe on HF radio waves. Sometimes the HF ionospheric mirror won't reflect at all or it will reflect waves in the wrong direction.



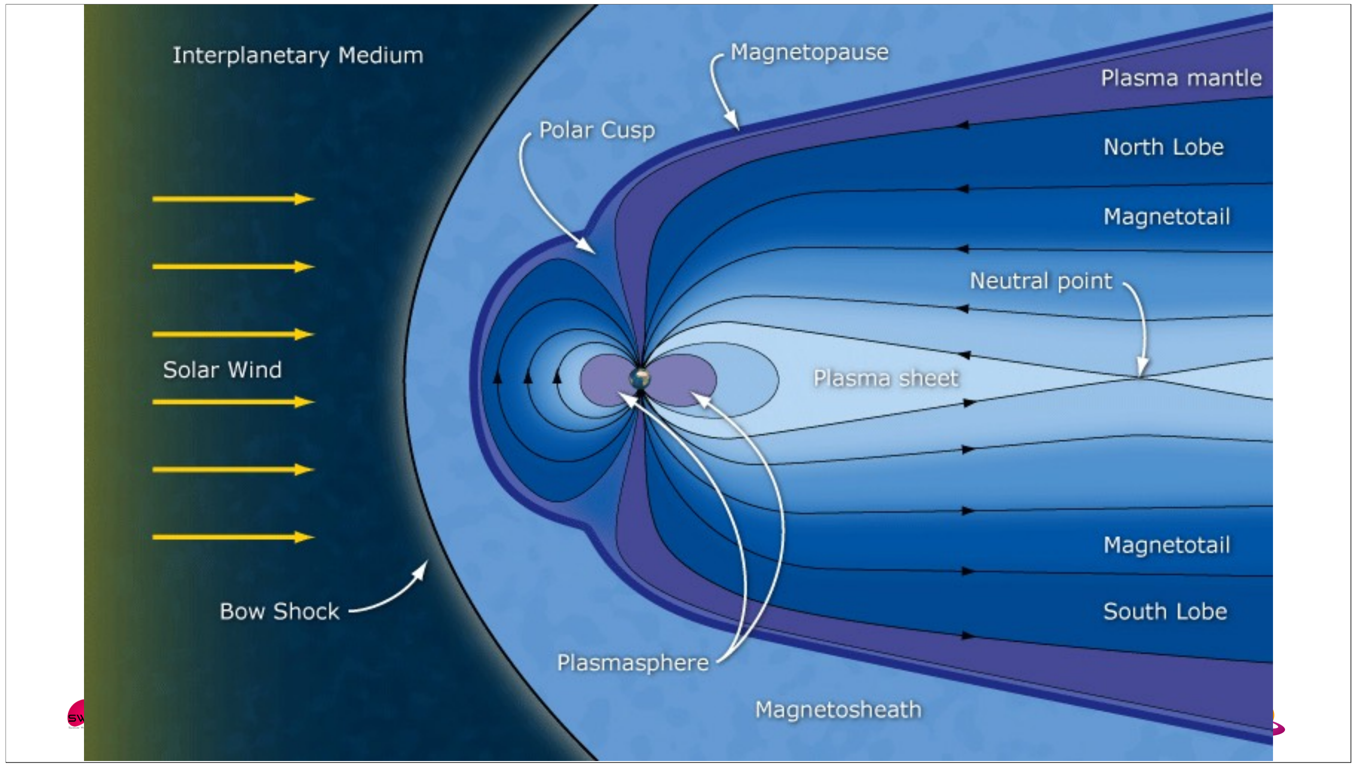
The geomagnetic field

The Earth has an internal magnetic field. That field is produced in the Earth's interior. It is changing slowly. (The magnetic poles move with a speed of about 10 km/year.)
It has this particular form due to the solar wind.

The magnetosphere is the region around Earth that is dominated by the geomagnetic field. The magnetospheric plasma originates in part in the ionosphere; the rest is captured solar wind material.



Donuts - radiation belts



The solar wind is a magnetized plasma. It encounters the environment of the Earth, which also turns out to be a magnetized plasma. Indeed, the Earth has an internal magnetic field. That field is produced in the Earth's interior. It is changing slowly. (The magnetic poles move with a speed of about 10 km/year.)

The magnetosphere is the region around Earth that is dominated by the geomagnetic field. The magnetospheric plasma originates in part in the ionosphere; the rest is captured solar wind material.

Magnetosphere is a highly dynamical system
https://www.researchgate.net/figure/Structure-of-Earth-magnetosphere-with-magnetopotentials-in-blue-inner-radiation-belt-in_fig3_351130787
Structure of Earth magnetosphere with magnetopotentials in blue, inner radiation belt in green, and outer radiation belt in red.

The magnetosphere consists of a (1) bow shock, where the solar wind (the stream of protons from the Sun) is slowed; (2) the magnetosheath behind the bow shock that contains thermalized solar plasma; (3) the magnetopause, where the thermalized solar plasma pressure is balanced by the plasma pressure generated by the magnetosphere; (4) the magnetotail, where the magnetic field is stretched out by the solar wind behind the dipole; and (5) the plasmasphere, where plasma is trapped by the magnetic field. The radiation belts are formed in the plasmasphere of the Earth's magnetosphere.

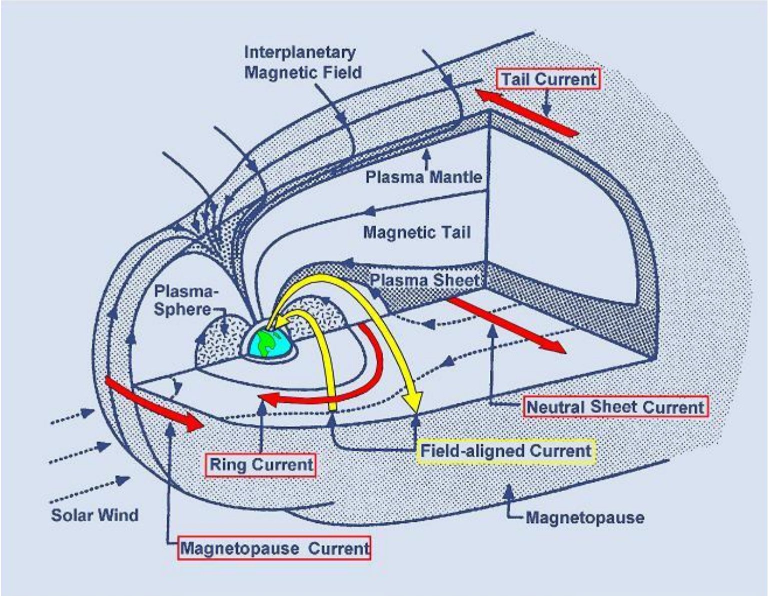
When the plasma up above is caused to move, magnetic field lines communicate this motion down to the ionosphere as if they were pieces of string tying the different plasma regions together.

Charged particles can move rather freely along field lines and therefore are good electric conductors. Electric currents flow along the field lines and connect magnetosphere and ionosphere. Therefore every electric feature in the magnetosphere has an "image" in the ionosphere, and conversely. We identify the following regions:

- Magnetopause ↔ footpoints of the cusps
- Tail lobes ↔ polar caps
- Plasma sheet ↔ auroral oval
- Plasmasphere ↔ ionosphere at low latitude

During low magnetic activity, the plasmasphere overlaps with the Van Allen radiation belts

Magnetospheric currents, connecting the solar wind to the thermosphere-ionosphere



https://www.youtube.com/watch?v=-hTNuJZByDc

The sharp limit of the plasmasphere is called the plasmapause.

The magnetopause interfaces two regions with different magnetic field. It therefore must be a current sheet : it carries the magnetopause current responsible for the change in magnetic field.

Magnetic reconnection
https://www.youtube.com/watch?v=QsGXN8Wf__o