

SPACE WEATHER INTRODUCTORY COURSE



Collaboration of



Solar-Terrestrial Centre of Excellence



Koninklijke luchtmacht

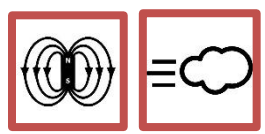


**Koninklijk Nederlands
Meteorologisch Instituut**
Ministerie van Infrastructuur en Milieu



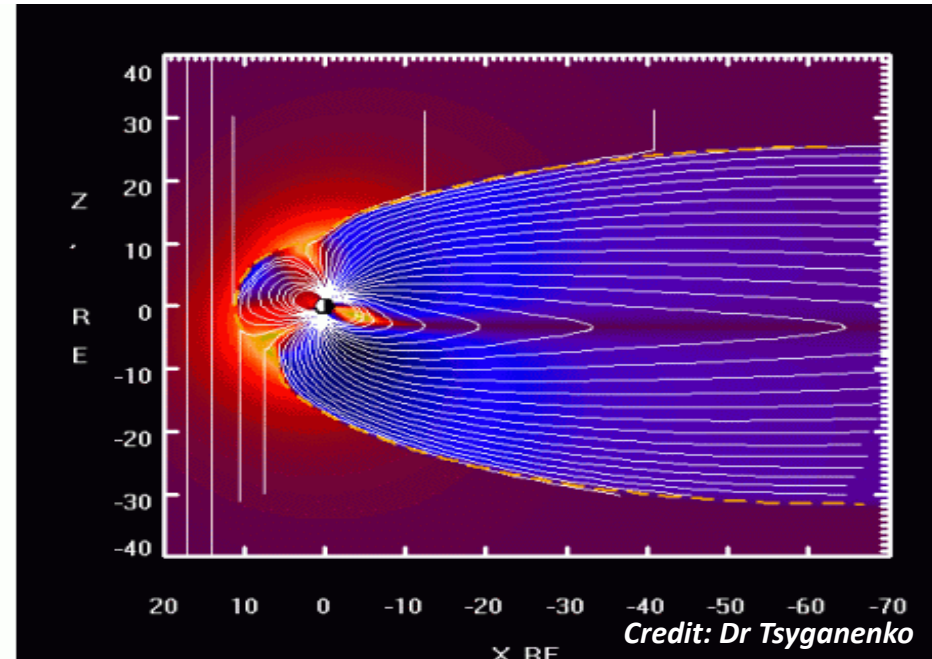
The Magnetosphere

Jan Janssens, Dr Johan De Keyser (BISA)



The magnetosphere

- ...that area of space, around a planet, that is controlled by the planet's magnetic field.
- Its ... shape is the direct result of being blasted by solar wind.
- Field lines connect the magnetosphere with the ionosphere



The Magnetosphere - Contents

- The geomagnetic field
- Main features
- Geomagnetic (sub)storms
- Measuring magnetic fields
 - Geomagnetic indices
 - Networks

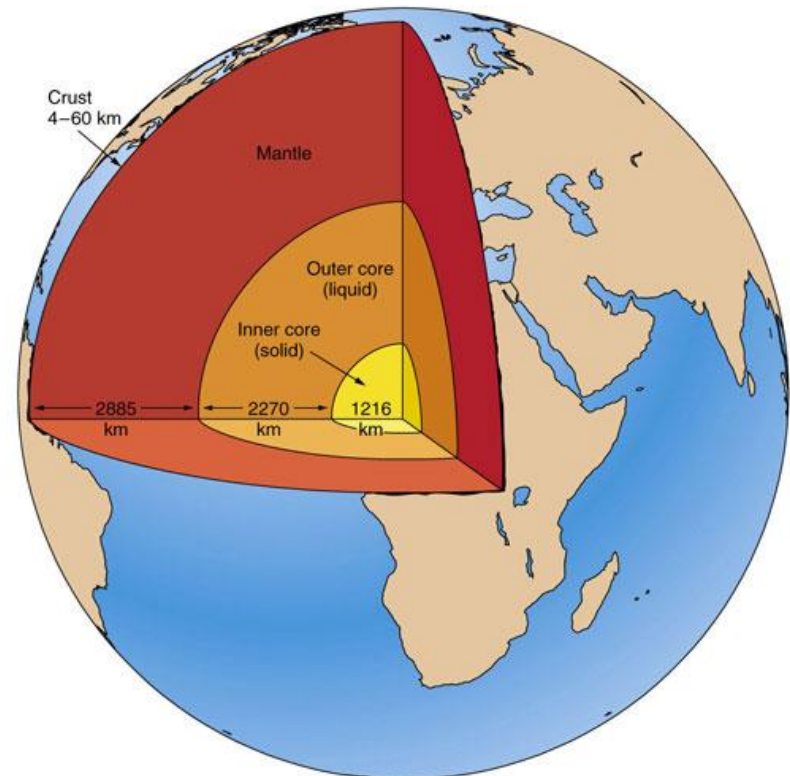
The Magnetosphere - Contents

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The geomagnetic field

- Created in and by the Earth's interior



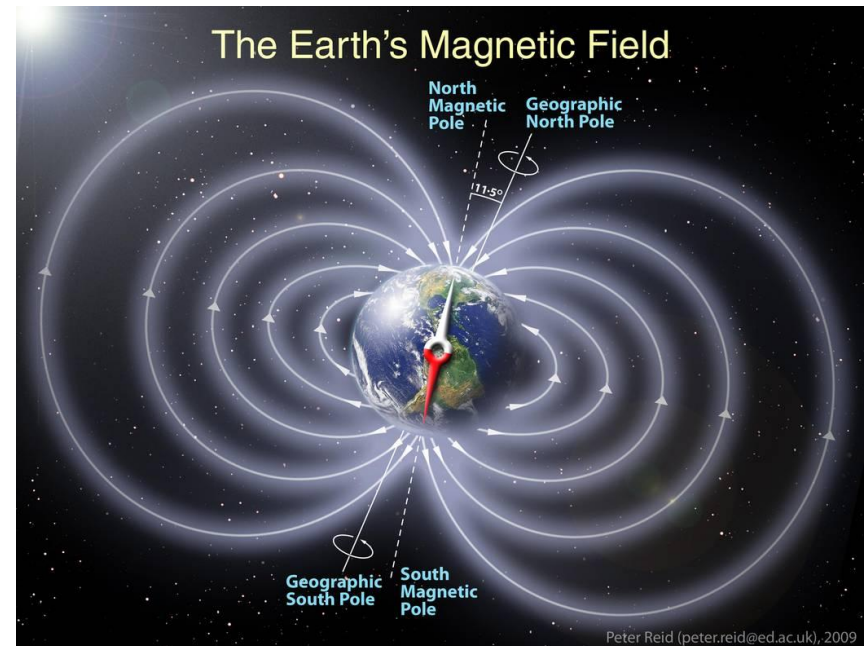
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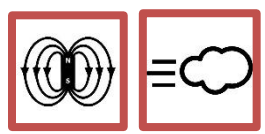




The geomagnetic field

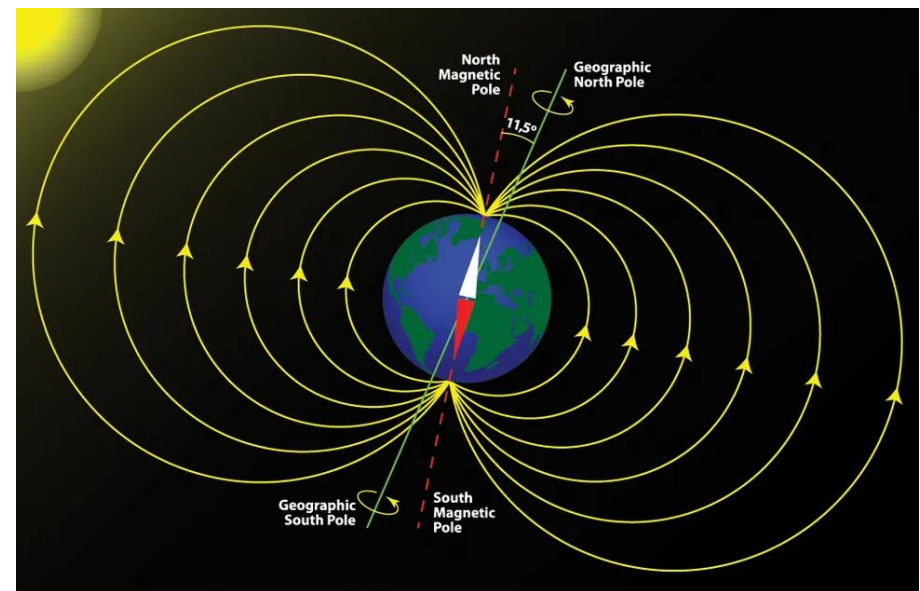
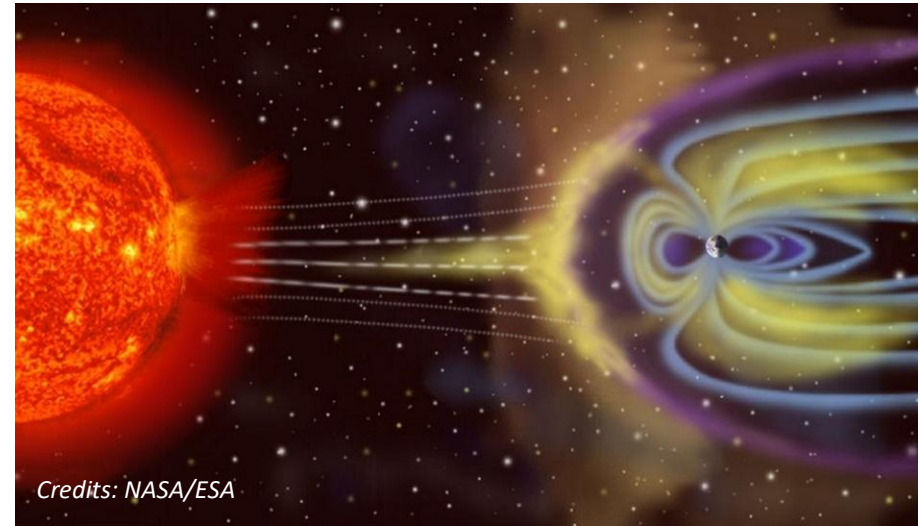
- Created in and by the Earth's interior
- Dipole (*not perfect*)
 - In absence of disturbances
 - Enters north pole (-), leaves at south pole (+)
 - Intensity:
 - 25000 – 65000 nT
 - Weakest at equator
 - Strongest at poles





The geomagnetic field

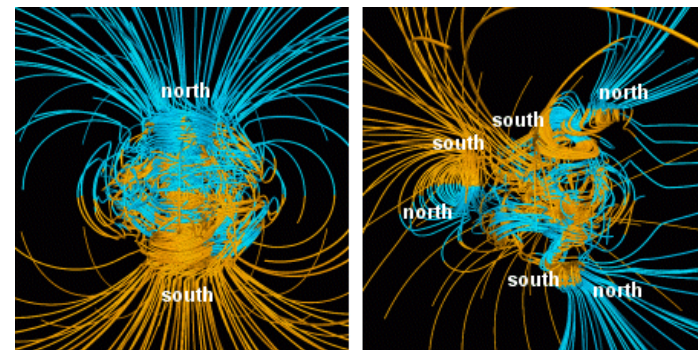
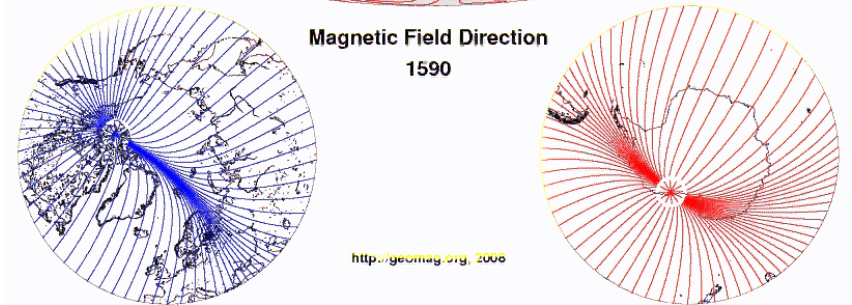
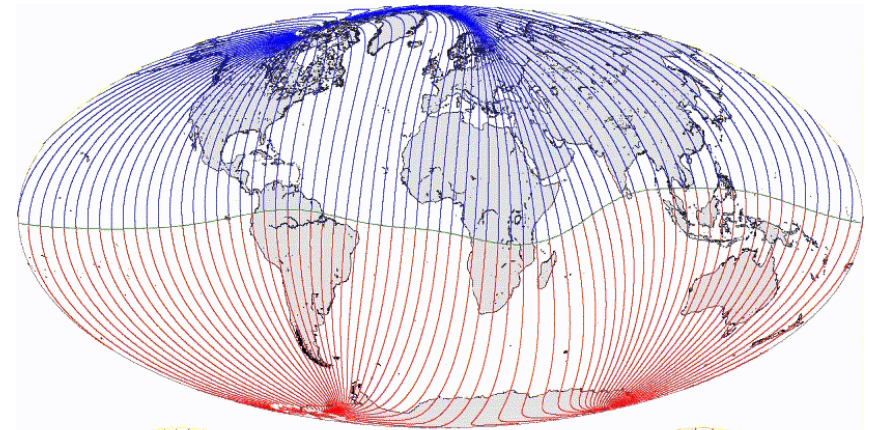
- Due to solar wind
 - Drop shape
 - $10 R_E$ (earth radii) at dayside
 - $>200 R_E$ at nightside
- Magnetic axis
 - 11° tilt to Earth's rotational axis
 - Compass does NOT point to true north
 - 500 km offset to north
 - Weakness over Brazil





The geomagnetic field

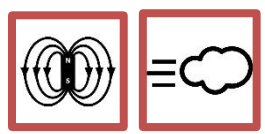
- Continuously changing
 - Short-term
 - Slow enough that compass remains useable
 - Airport runways
 - Long-term
 - Polar field reversals
 - Magnetic field does NOT disappear
 - Slow
 - Frequency: +/- 450000 years
 - » 250000 years overdue
 - Compare to Sun: 11 years!!



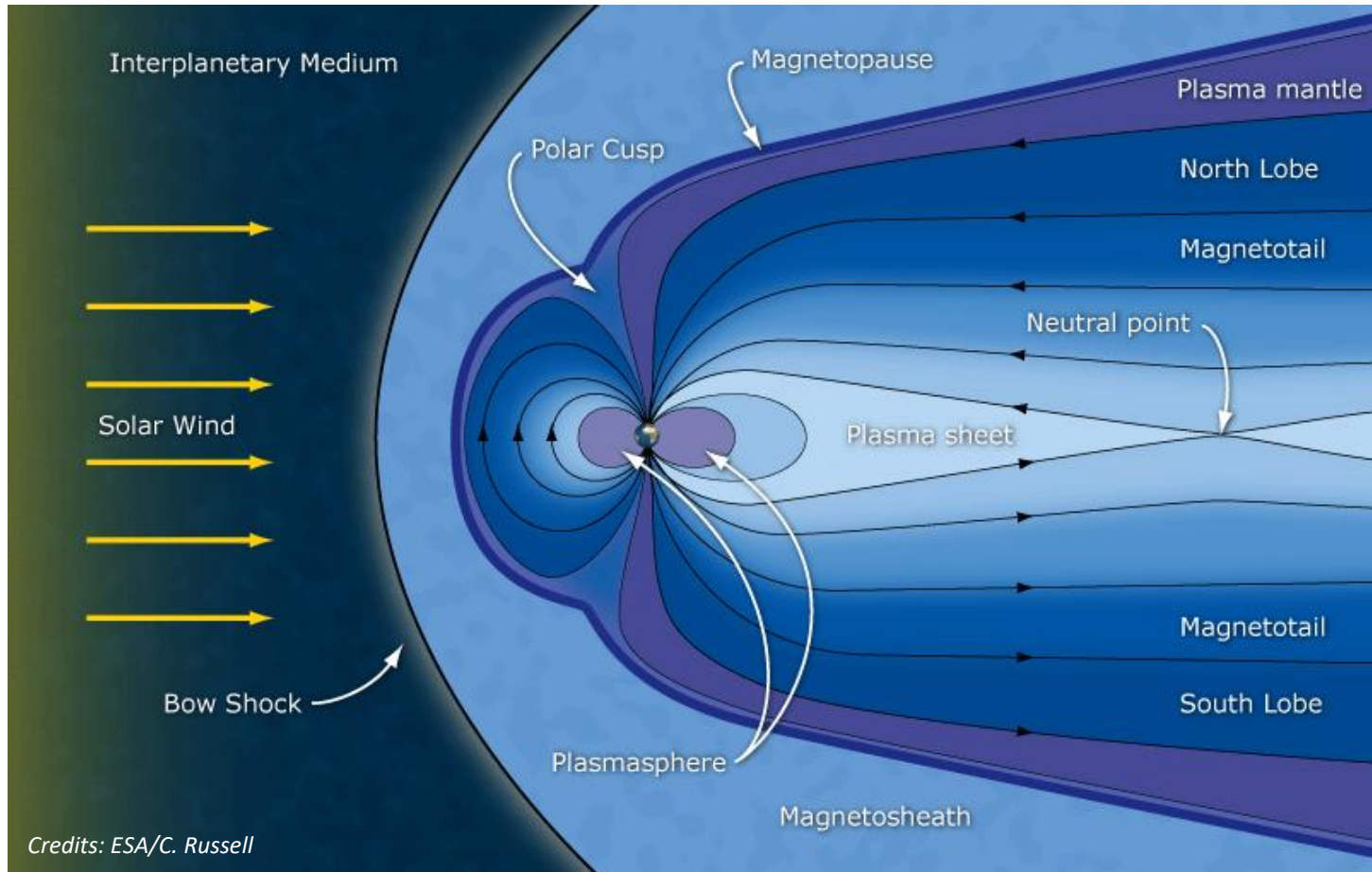
The Magnetosphere - Contents

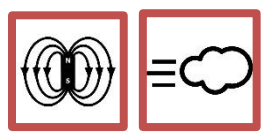
- The geomagnetic field
- **Main features**
- Geomagnetic (sub)storms
- Measuring magnetic fields
 - Geomagnetic indices
 - Networks



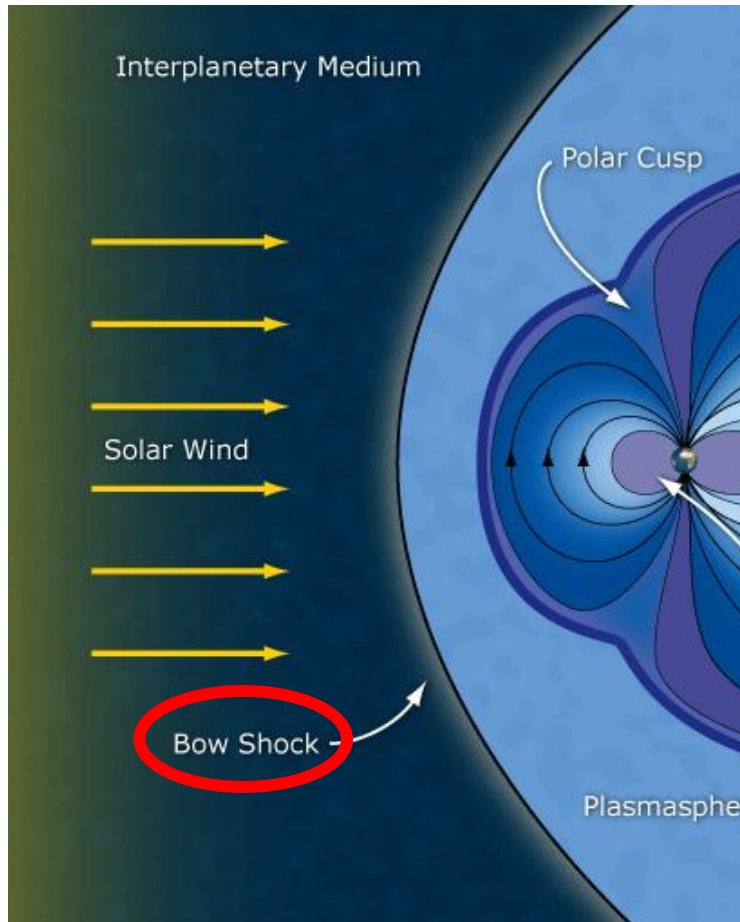


Main features

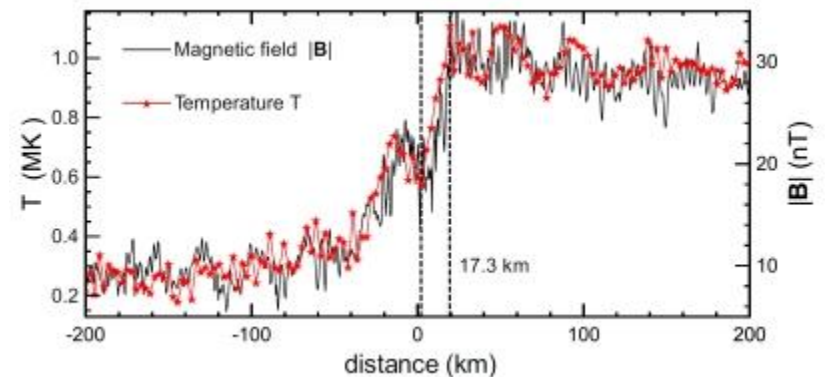


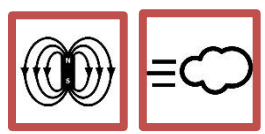


Main features

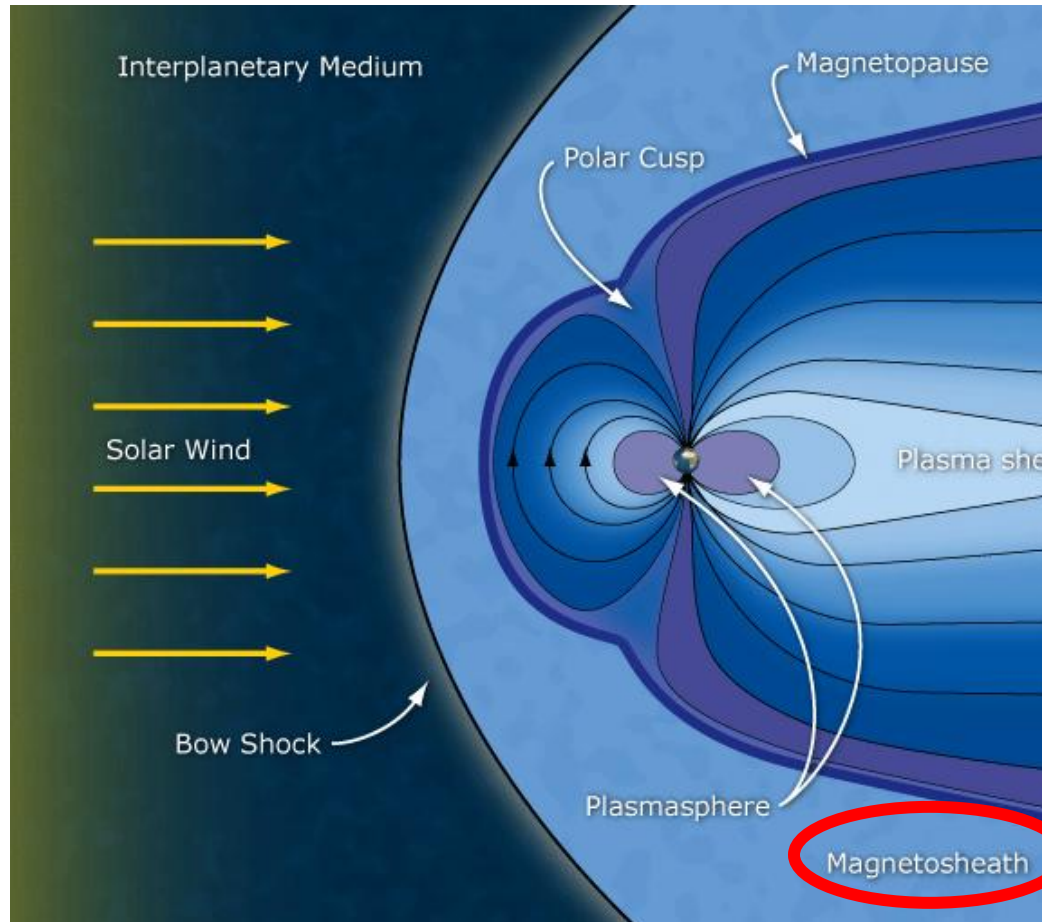


- Bow shock
 - First interaction w/ solar wind
 - Speed reduction
 - Increase T , B
 - Shock: very thin
 - Location
 - +/- 90.000 km upstream
 - Variable!

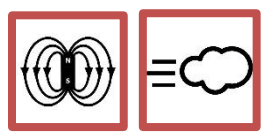




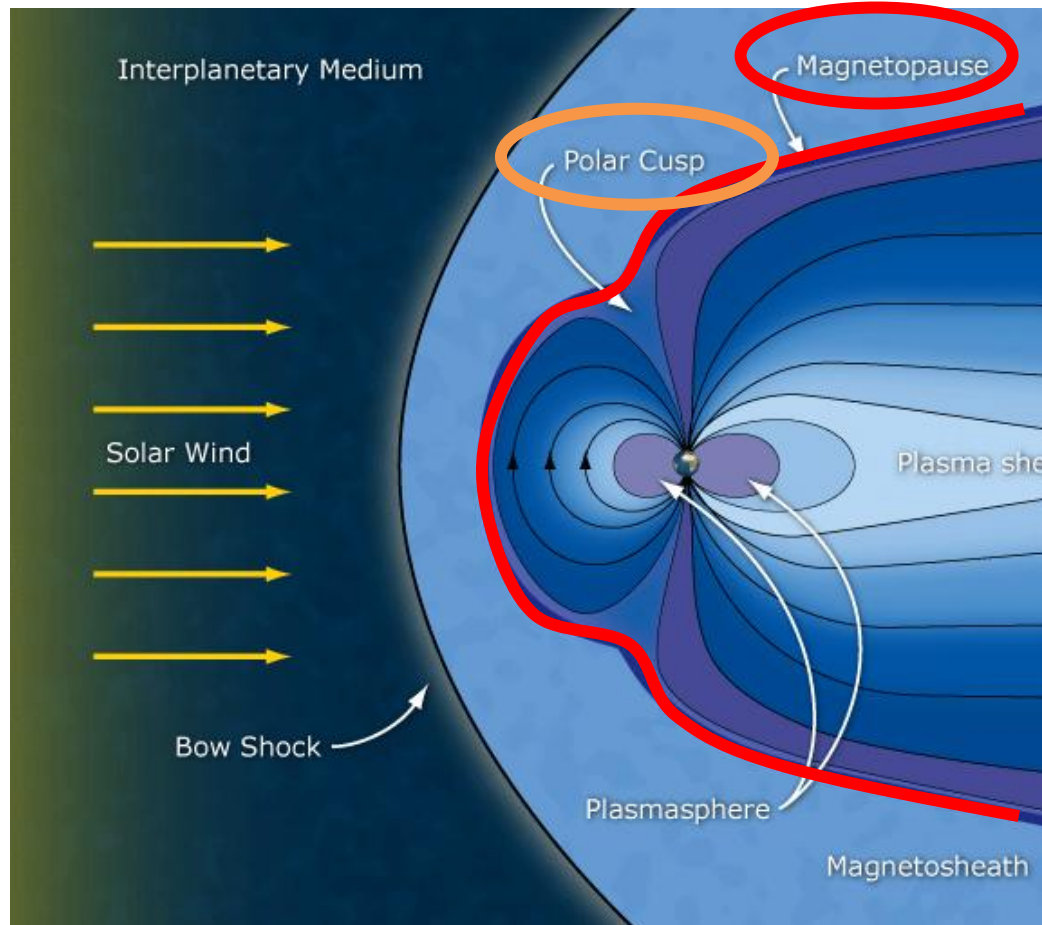
Main features



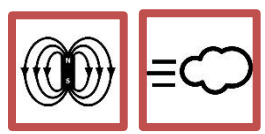
- Magnetosheath
 - Turbulent region between bow shock and magnetopause
 - Solar wind dominated
 - Deflected above and below the magnetopause
 - High particle energy flux
 - « shocked »
 - MF varies erratically
 - Much smaller than geomagnetic field



Main features

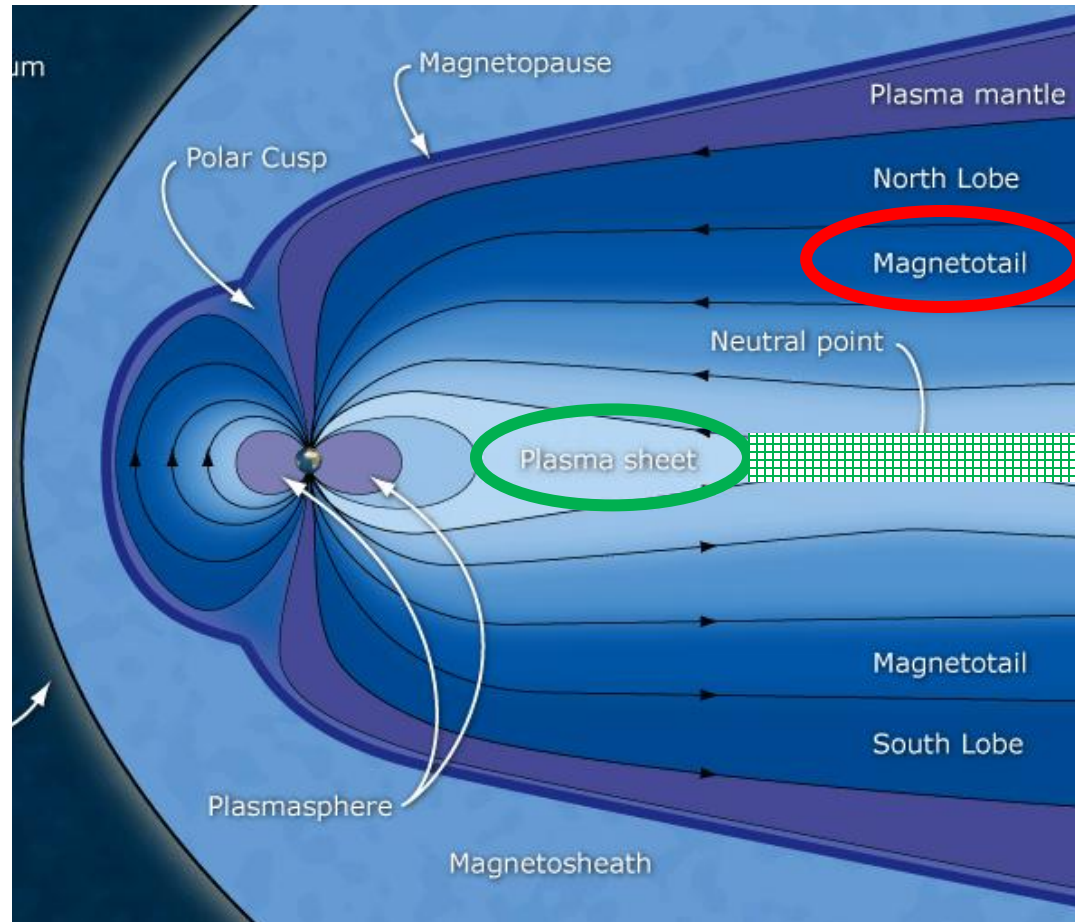


- Magnetopause
 - Sharp boundary
 - Pressure balance
 - = sum of magnetic + plasma pressure is constant
 - Earth vs. Solar Wind
 - Magnetic reconnection
 - Current sheet
 - Location:
 - 10-12 R_E (6-15 R_E)
 - **Cusp**
 - Narrow regions of opened/merged MF lines
 - In/outflow of particles



Main features

- Magnetotail
 - Several 100 R_E long
 - Two lobes
 - Northern: MF points towards Earth
 - Southern: MF points away from Earth
 - Separated by **plasma sheet**
 - Reconnection closer to Earth during strong disturbances
 - Source of aurora

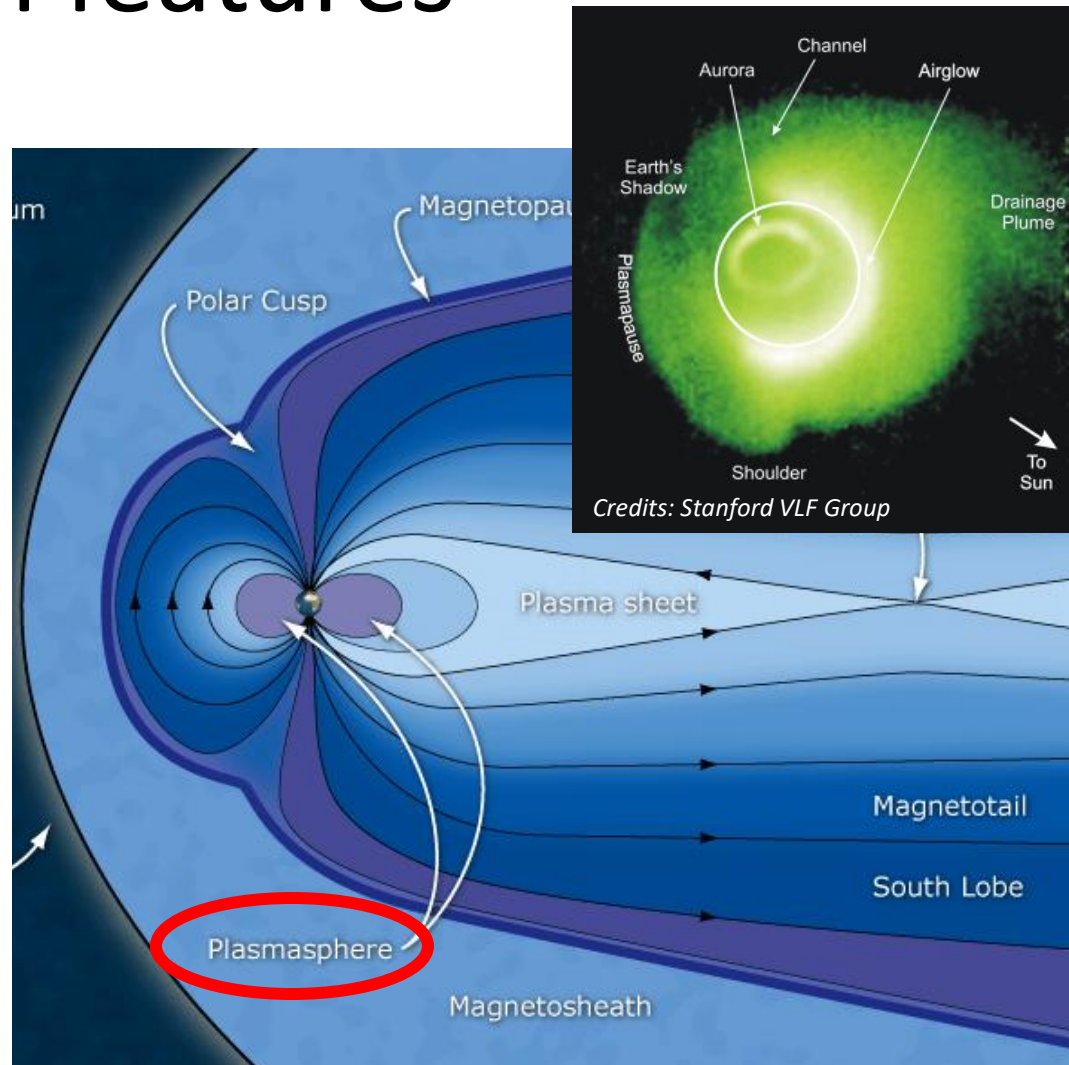


R_E : Earth radii ; MF: Magnetic Field



Main features

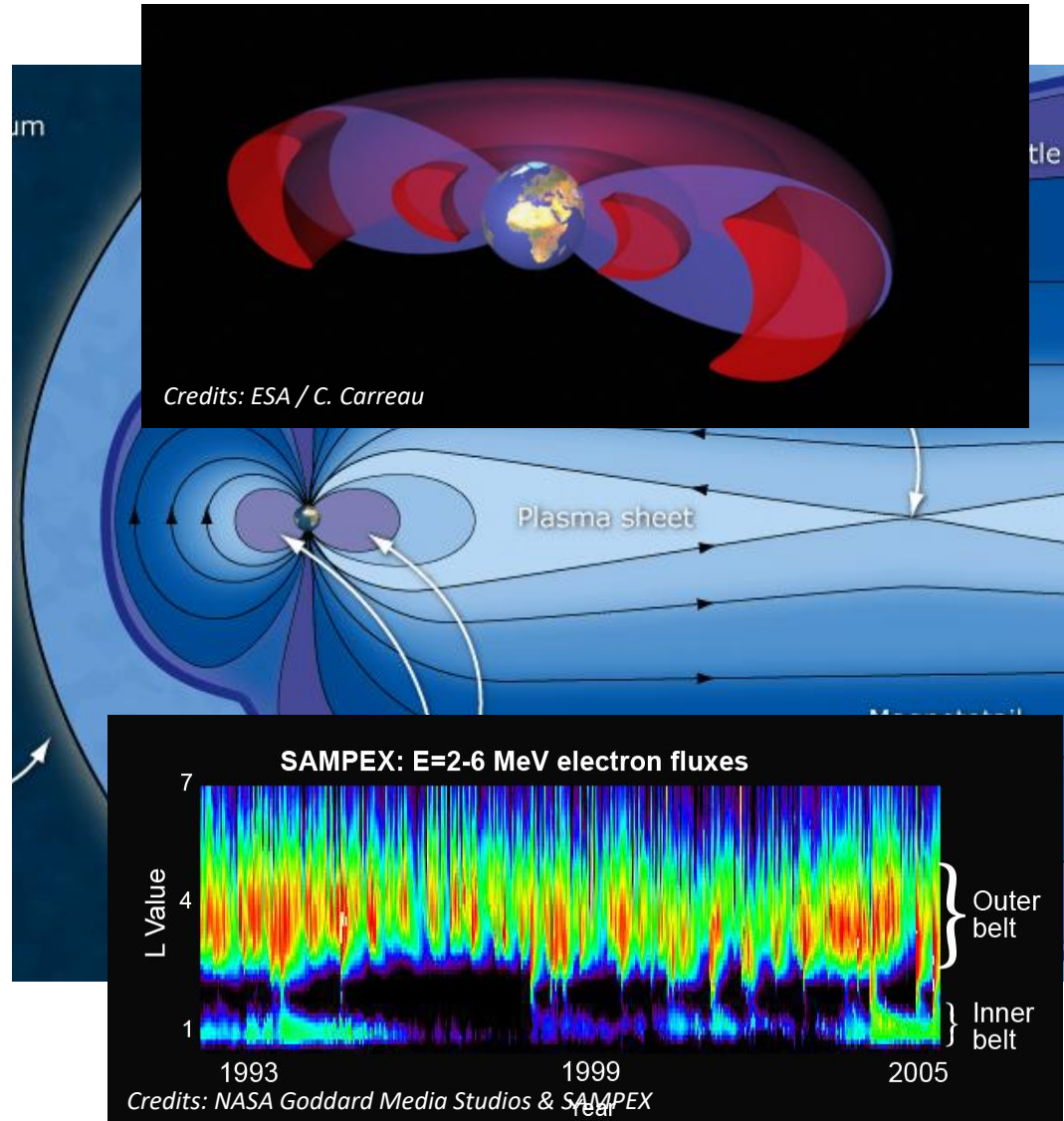
- Plasmasphere
 - Donut shaped region
 - Specific features
 - Cold plasma
 - From ionosphere
 - Strong geomagnetic storms
 - Plasmapause moves closer to inner boundary of outer region
 - « Erosion » of the plasmasphere





Main features

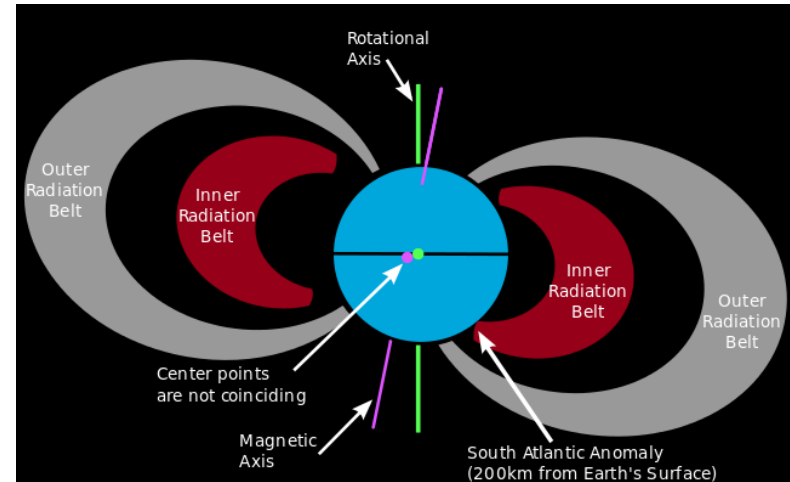
- Radiation belts
 - Outer belt
 - Mostly electrons (e^-)
 - 0.1-10 MeV
 - 3-8 earth radii
 - Inner belt
 - Mostly protons (p^+)
 - 10-500 MeV
 - 1.2-2 earth radii
 - Separated by slot region
 - Strong geomagnetic storms
 - Injection of $> 15\text{MeV } p^+$ and $> 3\text{MeV } e^-$ which can reach all the way down into the Inner Radiation Belt



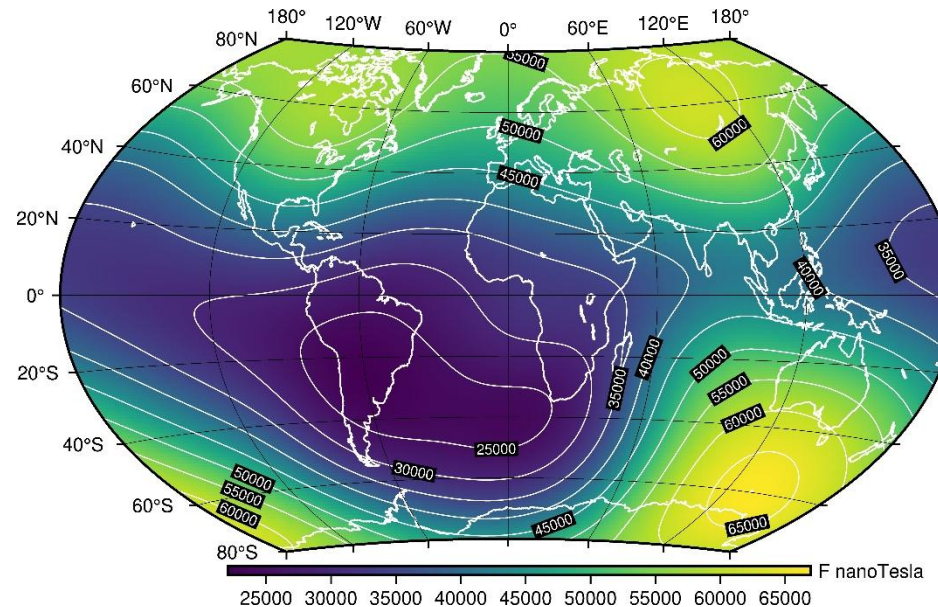


Main features

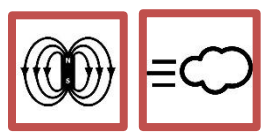
- Radiation belts
 - South Atlantic Anomaly (SAA)
 - Extension of Inner belt closest to Earth
 - altitude: 200 km
 - Over Brazil
 - » Drift westward at 3°/decade



Credits: Marko Markovic

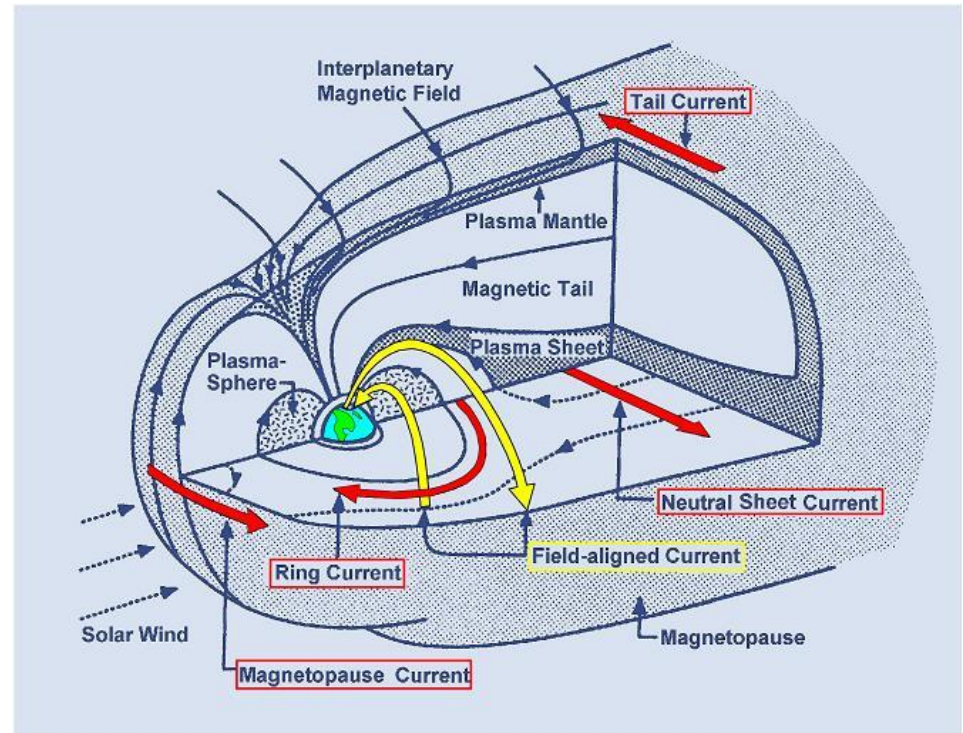


Credits: BGS/IGRF14



Main features

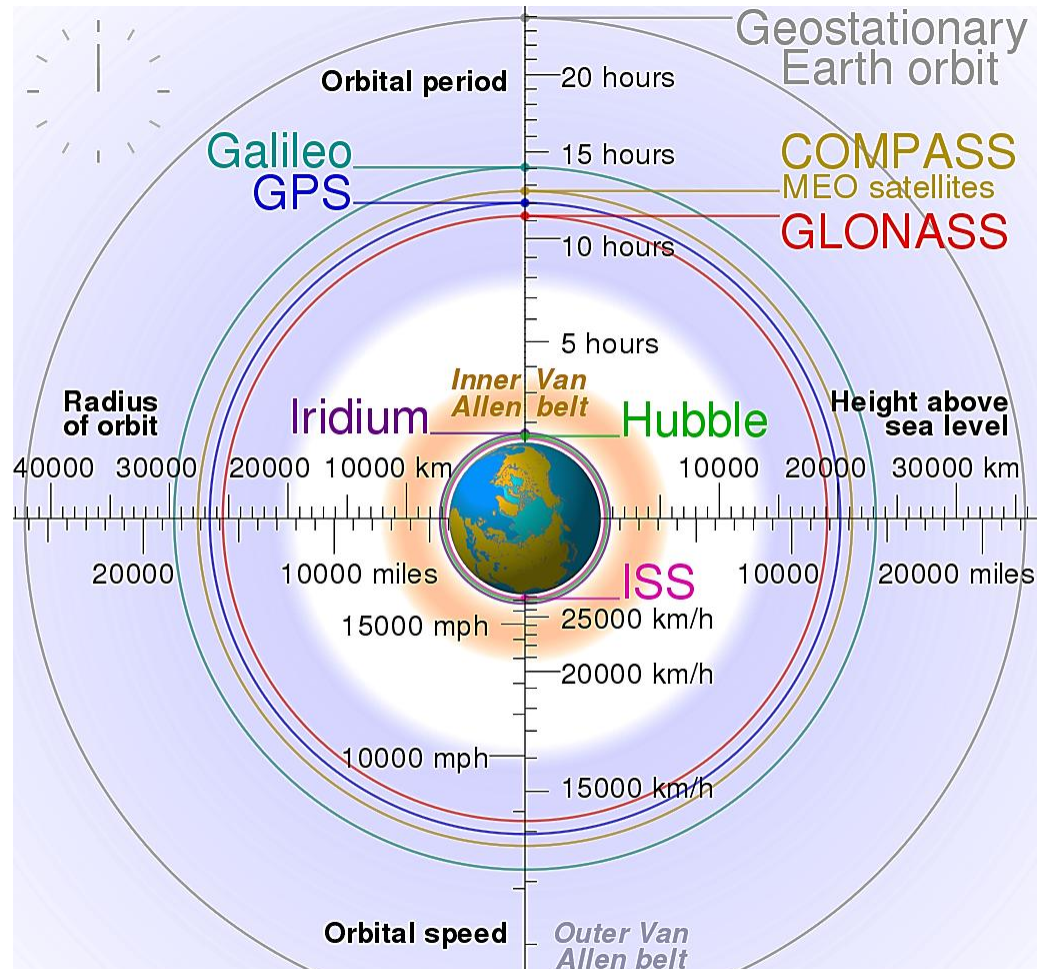
- Magnetospheric Currents
 - Magnetopause current
 - Ring current
 - Field-Aligned Current (FAC)
 - Neutral sheet current
 - Tail current





Main features

- Satellite Earth orbits



ORBIT NAME	ORBIT INITIALS	ORBIT ALTITUDE (KM ABOVE EARTH'S SURFACE)
Low Earth Orbit	LEO	200 - 1200
Medium Earth Orbit	MEO	1200 - 35790
Geosynchronous Orbit	GSO	35790
Geostationary Orbit	GEO	35790
High Earth Orbit	HEO	Above 35790





Main features

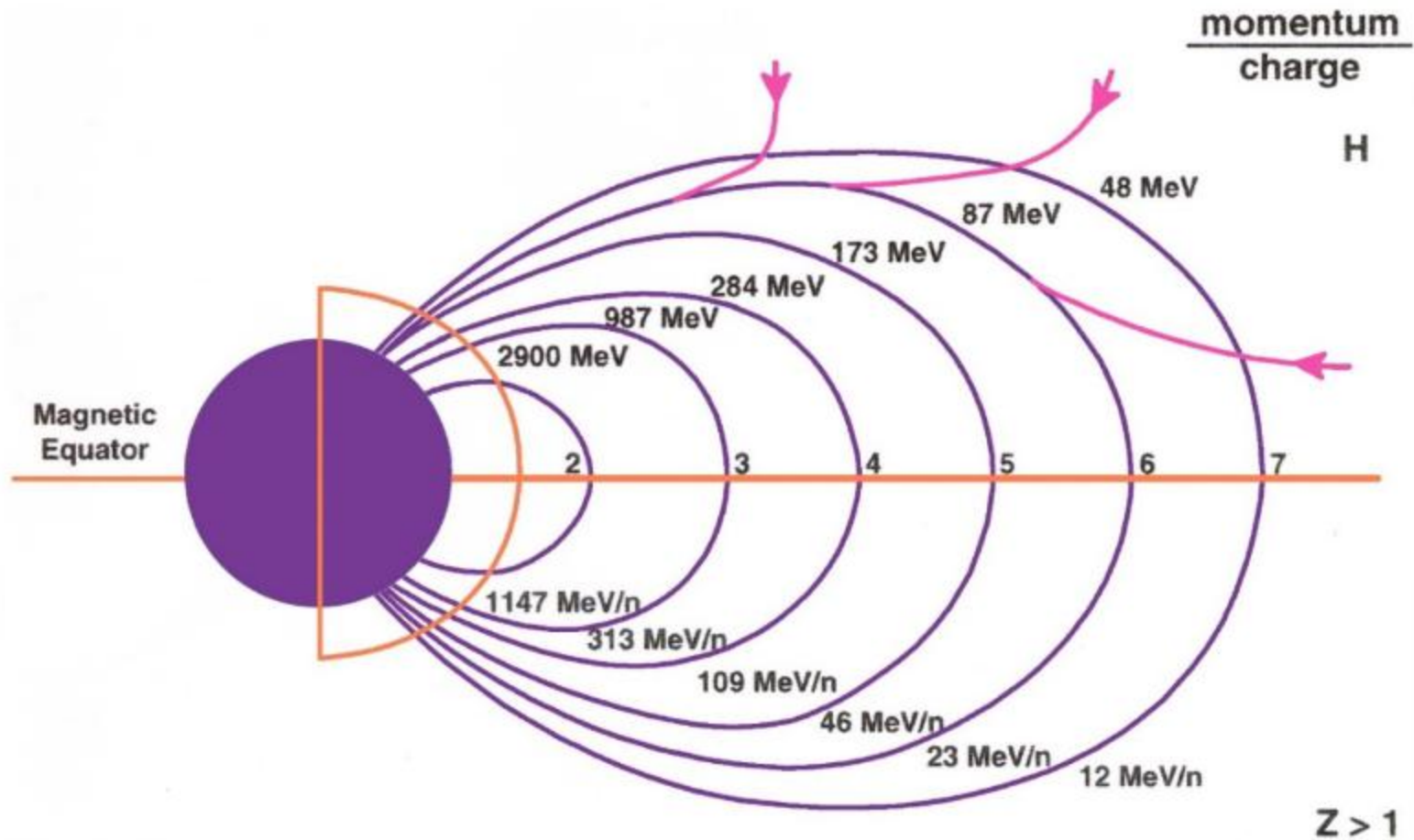
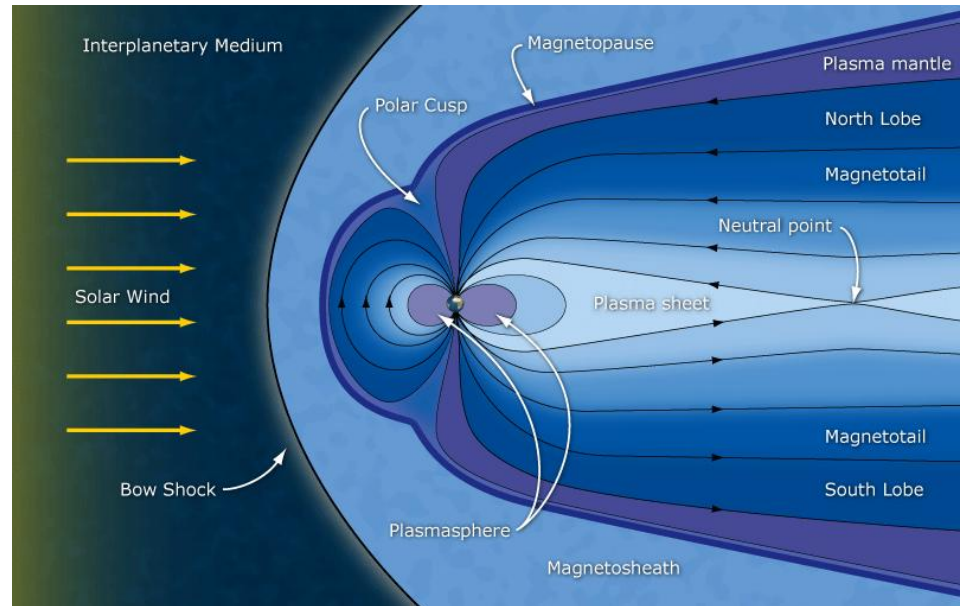


Figure 66: L-shell contours with rigidity imposed energy penetration limits.

Exercise: Magnetosphere

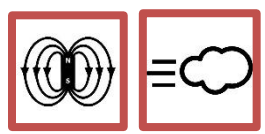
- The magnetosphere
 - a. Stretches all the way to the bow shock
 - b. Stretches all the way to the magnetopause
 - c. Contains only specific areas such as the radiation belts



The Magnetosphere - Contents

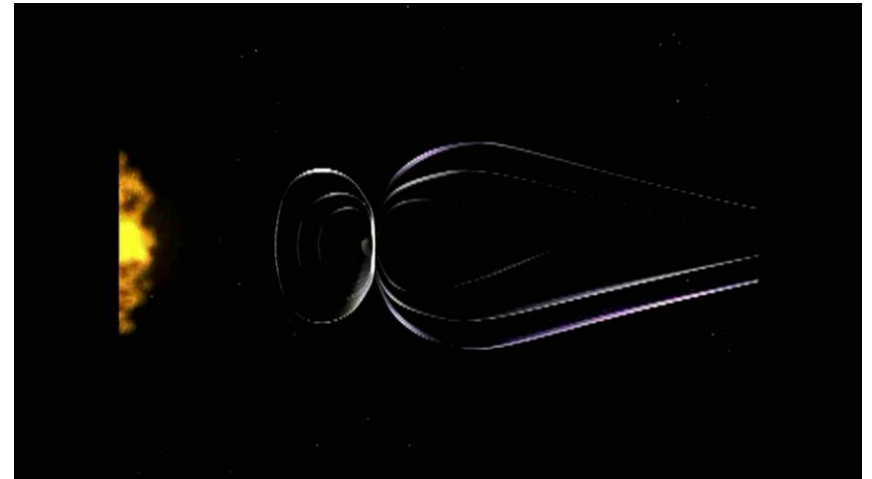
- The geomagnetic field
- Main features
- **Geomagnetic (sub)storms**
- Measuring magnetic fields
 - Geomagnetic indices
 - Networks

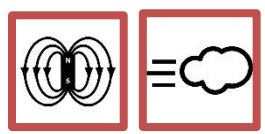




Geomagnetic (sub)storm

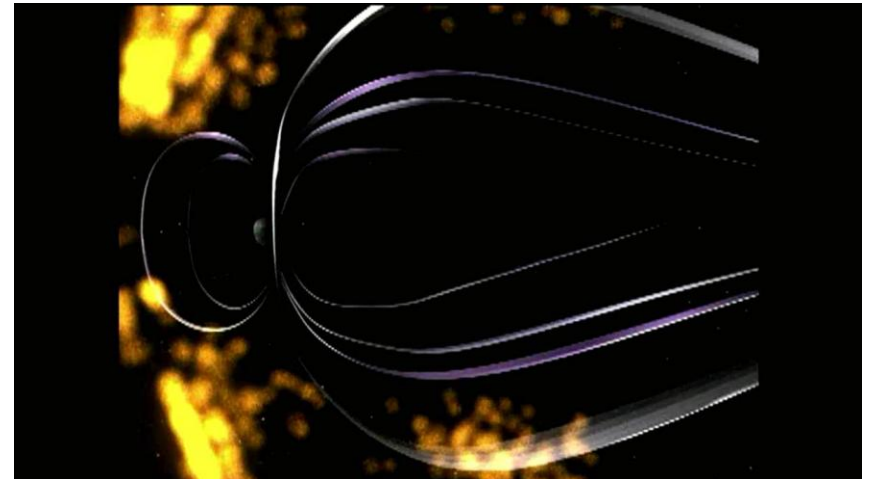
- Growth phase
 - Reconnection at magnetopause
 - Magnetic erosion
 - Open field lines are swept back into magnetotail
 - Some particles get access via cusps
 - Building of magnetic flux in magnetotail

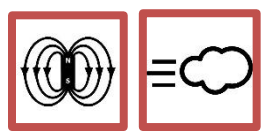




Geomagnetic (sub)storm

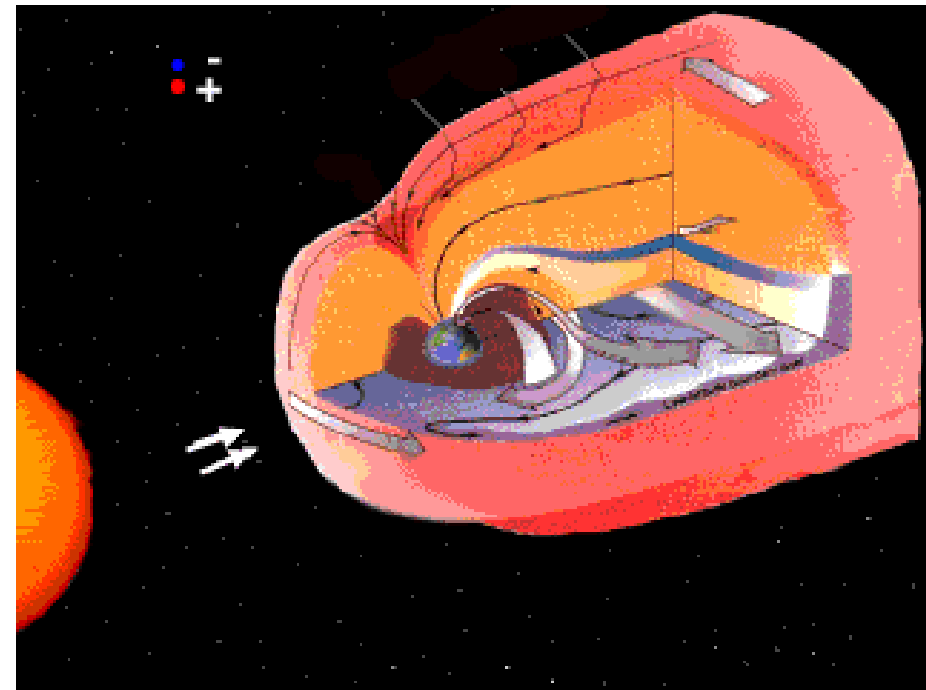
- Expansion phase
 - Explosive release of built-up energy in magnetotail
 - Particles get accelerated to Earth
 - Aurora, Ring current enhancement,...
 - A plasmoid gets ejected tailward back into solar wind





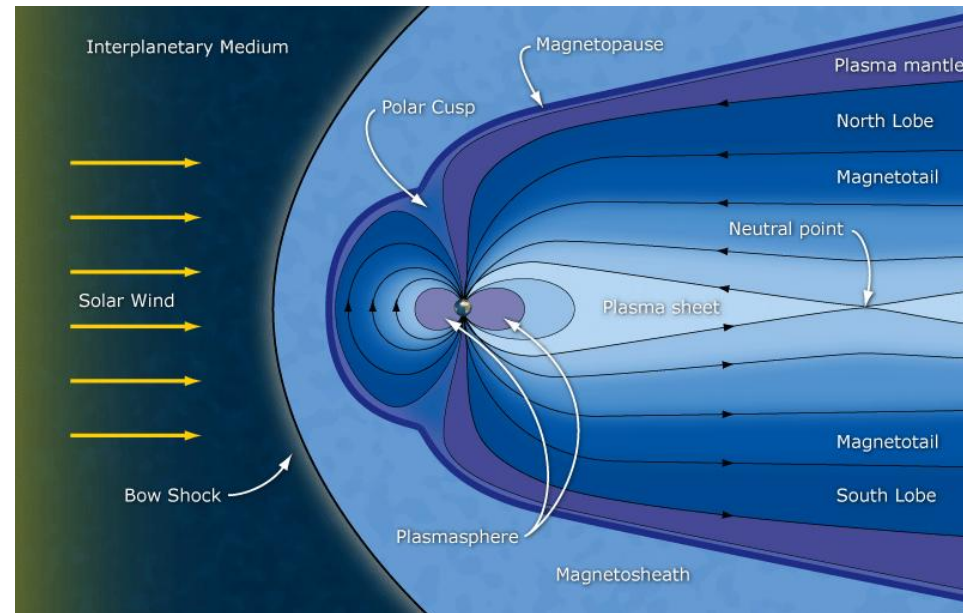
Geomagnetic (sub)storm

- In summary
 - Growth phase
 - Reconnection at magnetopause
 - Expansion phase
 - Reconnection in near-tail
 - Particle acceleration
 - Recovery phase
- 4 to 5 substorms / day
 - Energy input of 30-60'
 - 2-3 hours each
- If energy input > 3 hrs
 - Development of geomagnetic storm



Exercise: Geomagnetic (sub)storms

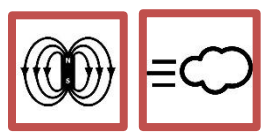
- In the magnetosphere, magnetic reconnection can take place:
 - a. Near the magnetopause
 - b. In the plasmasheet
 - c. In the plasmasphere
 - d. In the Van Allen radiation belts



The Magnetosphere - Contents

- The geomagnetic field
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Geomagnetic indices

- Measure for geomagnetic unrest
- Ground-based magnetometer networks
 - Intensity and changes in intensity of the geomagnetic field
 - Corrected for diurnal and seasonal variations (quiet Sun)

The K index is derived from the amplitude of the variations of the field's horizontal components (the H and D pair, or alternatively, the X and Y components) after subtracting the daily solar regular (S_R) variation for the particular component (cf. Fig.2).

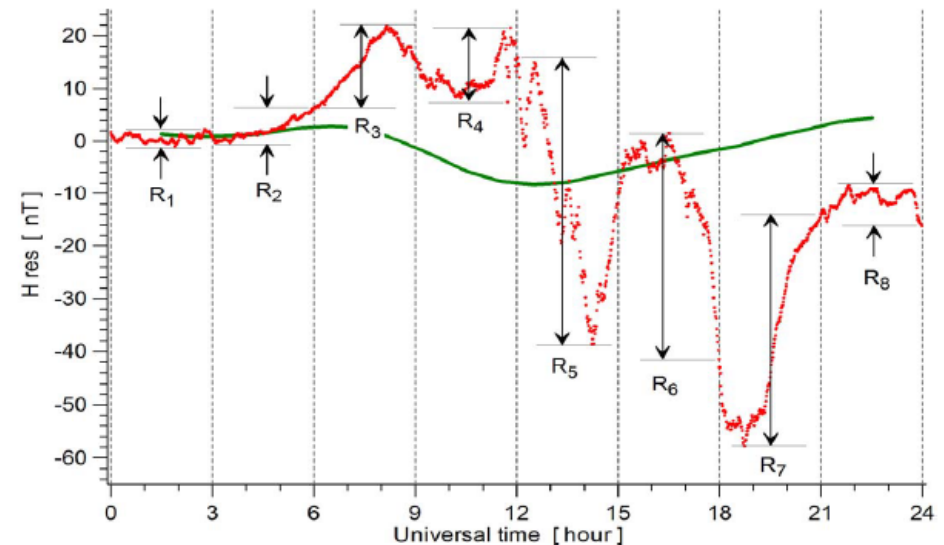
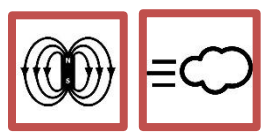


Fig.2. Calculation of the 3-hour K index over a 24 hour period. A daily record of 1-min measurements of the H component is presented here to illustrate the elimination of the solar regular variation, the S_R curve (the solid line), and the consequent determination of the 8 ranges (R_i , $i=1,8$). The difference between the upper (maximum) and lower (minimum) envelopes that are parallel to the S_R curve, determines the disturbance range within every 3-hour interval.





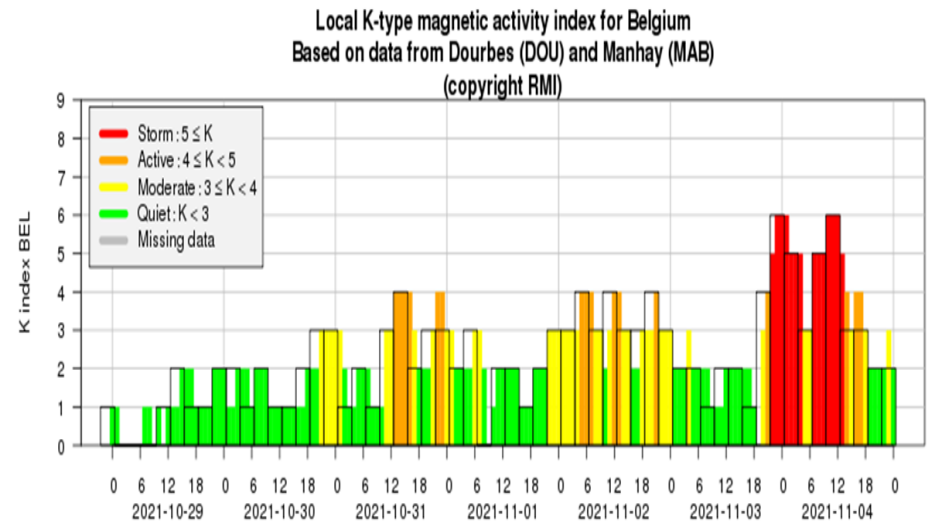
Geomagnetic indices

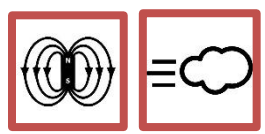
K index

- Kennziffer
- Local
 - E.g. Dourbes
- Quasi-logarithmic scale
- Expressed in full units
 - 0, 1, ... , 9
- 3hrs interval
 - 0-3UT, ... , 21-24UT
 - 1hrs possible (Dourbes)

K_{Belgium}

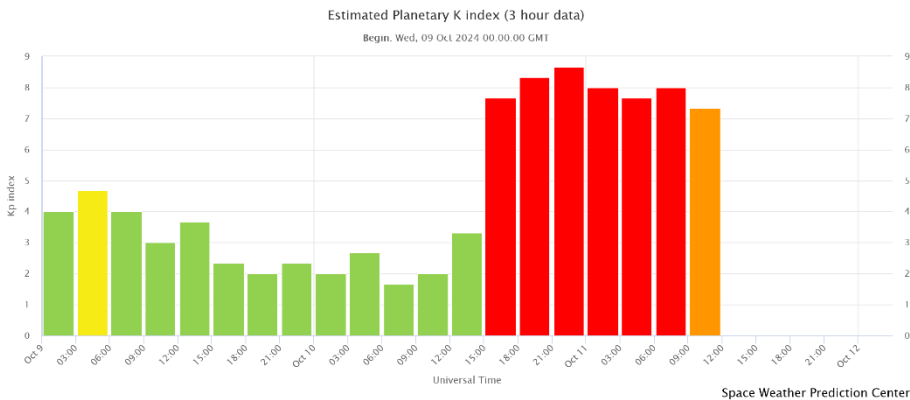
- RMI Geophysical Centre of Dourbes
 - 2 local K-indices (Dourbes, Manhay)





Geomagnetic indices

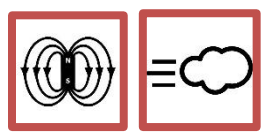
Estimated Kp (NOAA/SWPC)



Kp index

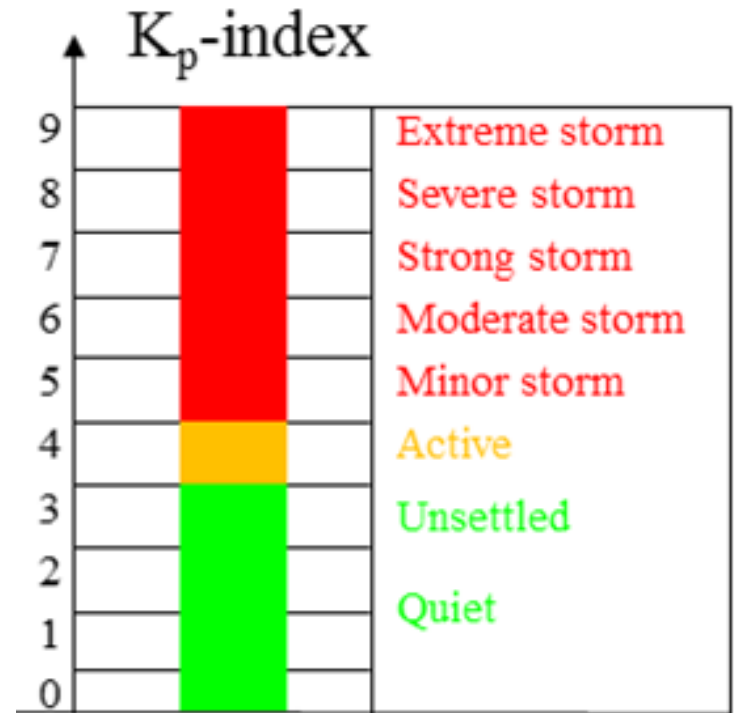
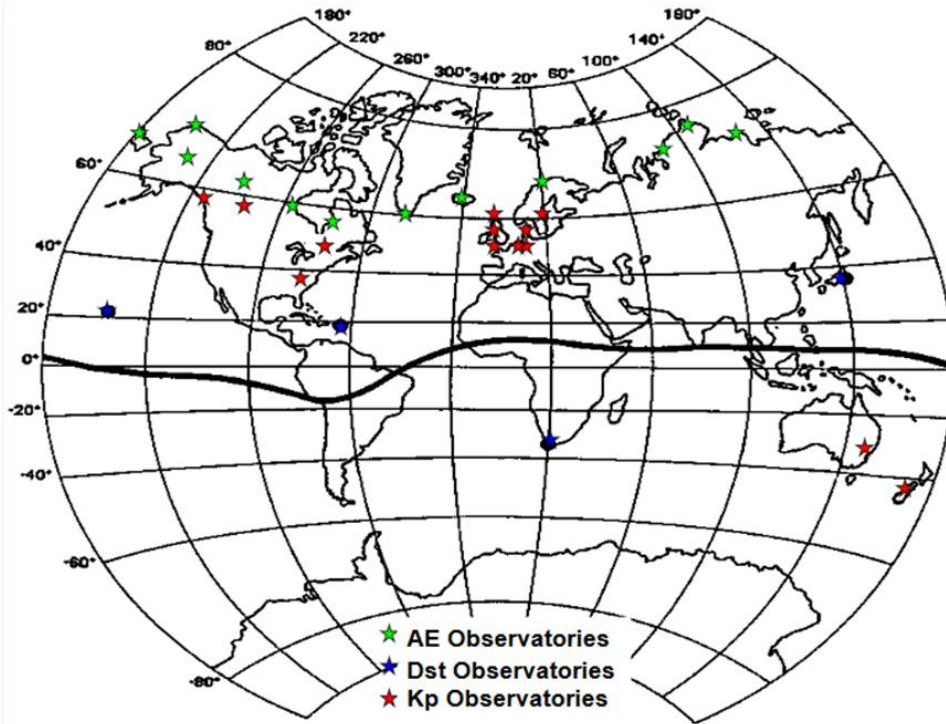
- Planetary Kennziffer
- From network
 - 13 observatories (subauroral)
- Quasi-logarithmic scale
- Expressed in 1/3
 - 0o, 0+, ... => ... , 9-, 9o
- 3hrs interval
 - 0-3UT, ... , 21-24UT
- Used in NOAA scales (G)
 - Auroral visibility maps
- Estimated Kp
 - Final Kp: GFZ Potsdam
 - <https://kp.gfz-potsdam.de/en/>
- Going back to 1932

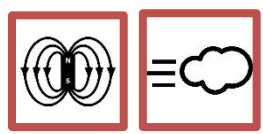




Geomagnetic indices

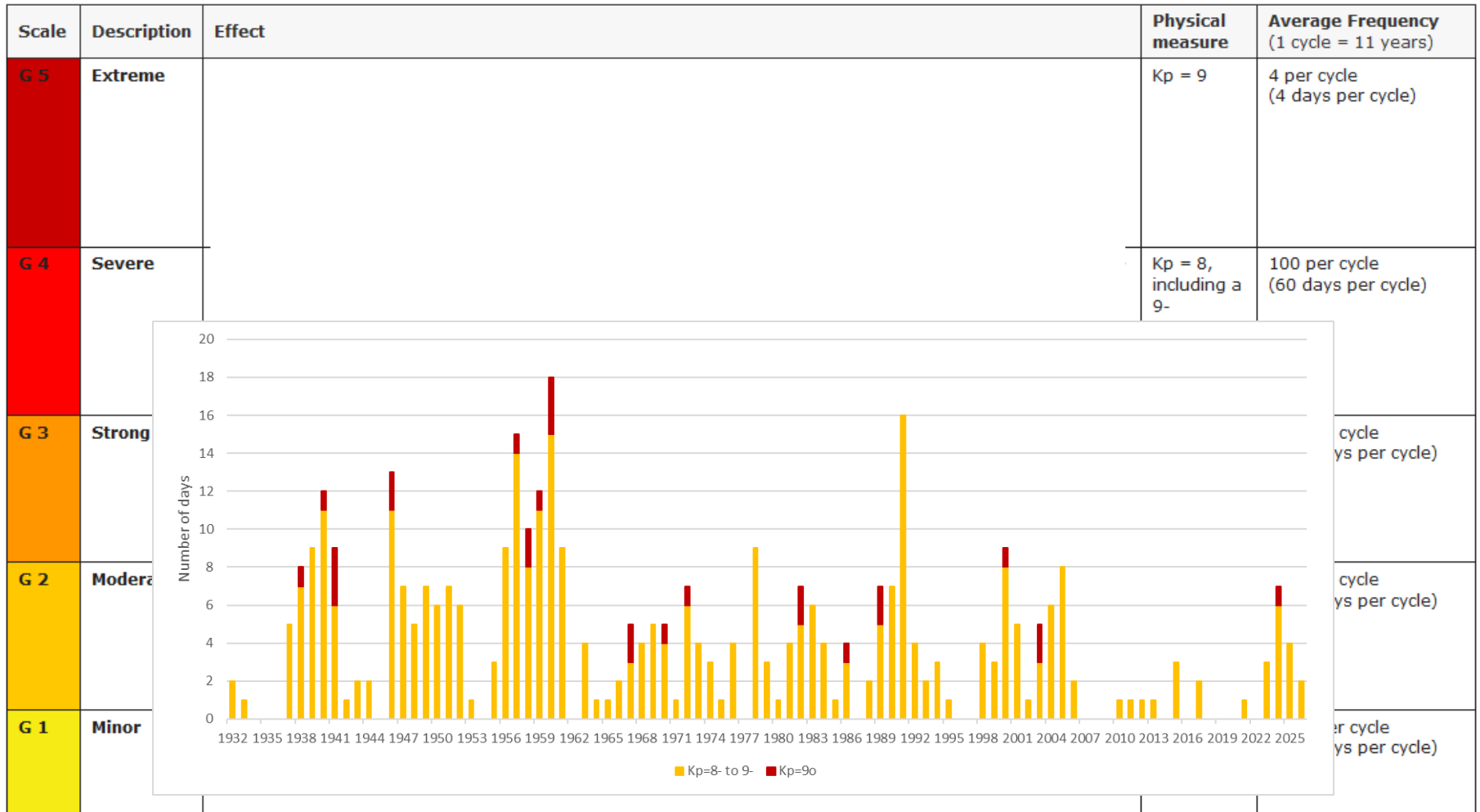
- Observatories
- Nomenclature

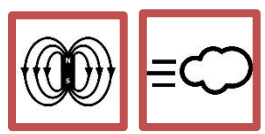




Geomagnetic indices

- NOAA-scales: G-scale

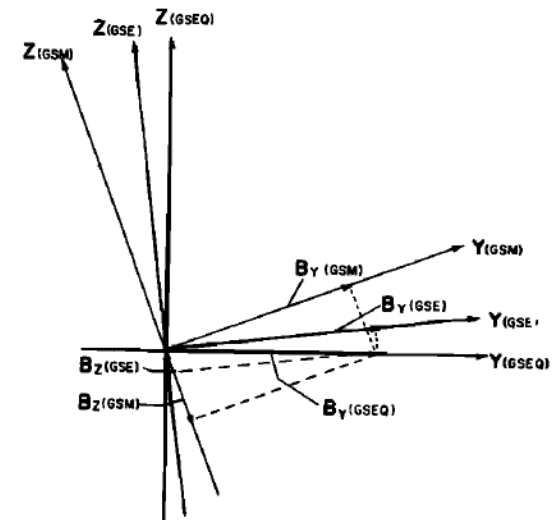
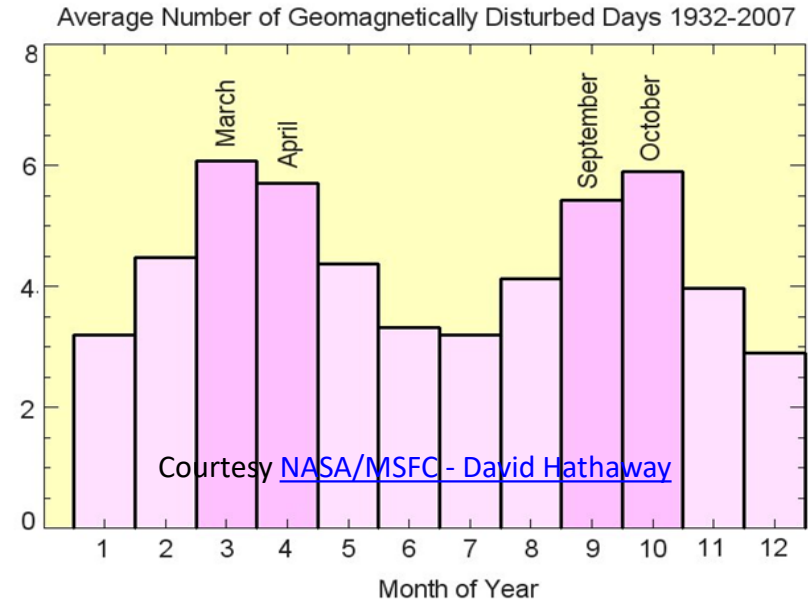


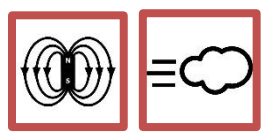


Miscellaneous 1

- Seasonal variation
 - More geomagnetic storms during equinoxes than during solstices
 - Probable explanation by Russell & McPherron (1973)

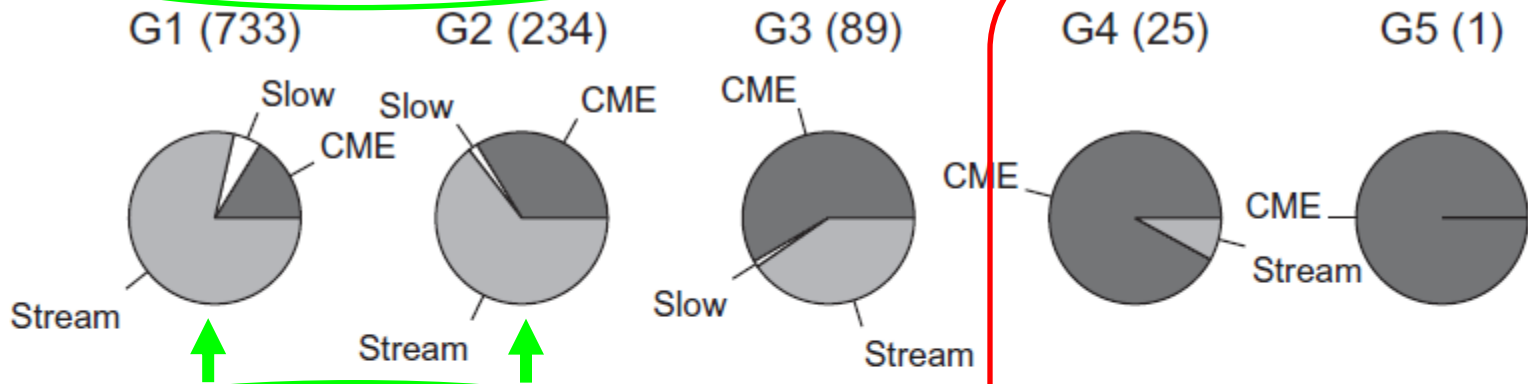
Fig. 4. One of the possible orientations of the Y - Z planes of the solar equatorial (GSEQ), solar ecliptic (GSE), and solar magnetospheric (GSM) coordinates, showing how a vector in the solar equatorial plane can have a southward (along the $-Z$ axis) GSE and GSM component.



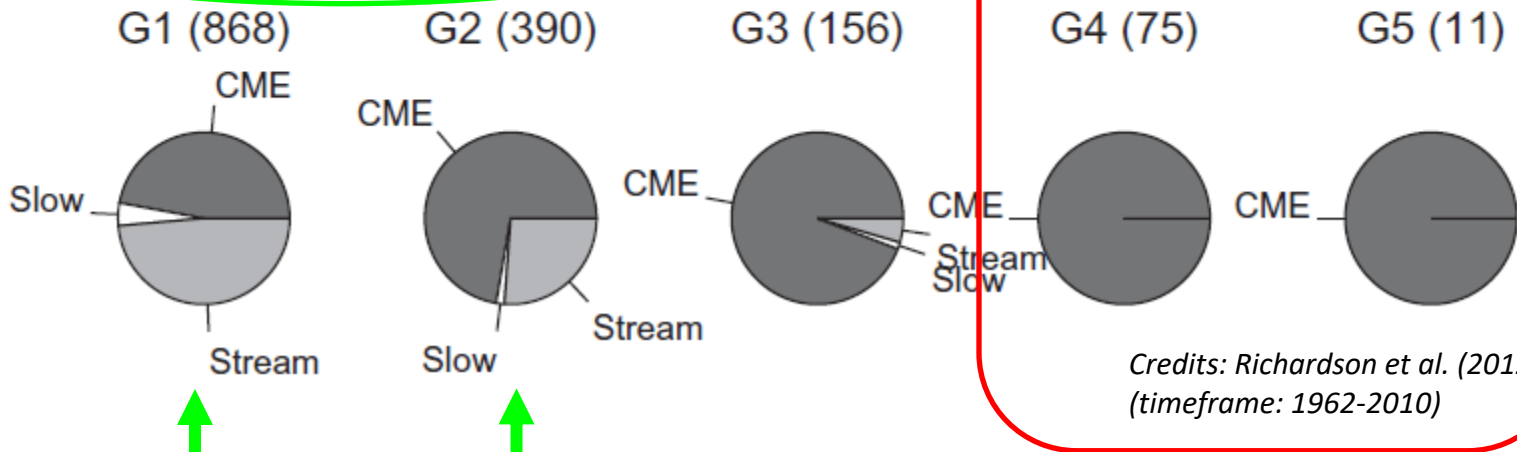


Miscellaneous 2

Solar Minimum Storms (Smoothed sunspot number < 40)

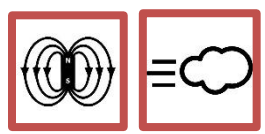


Solar Maximum Storms (Smoothed sunspot number > 40)



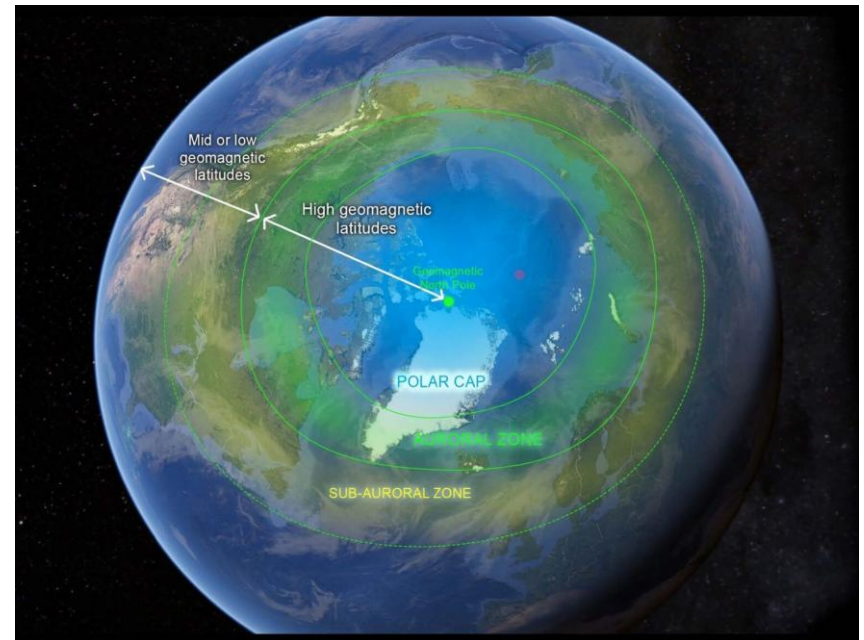
Credits: Richardson et al. (2012)
(timeframe: 1962-2010)



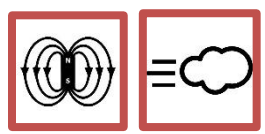


Geomagnetic indices

- Ap, ap
 - Derived from Kp
 - Subauroral stations
 - Required for daily averaging
 - « ap » value per interval (Kp)
 - Ap is the average of the 8 ap values for that day
 - Expressed in nT

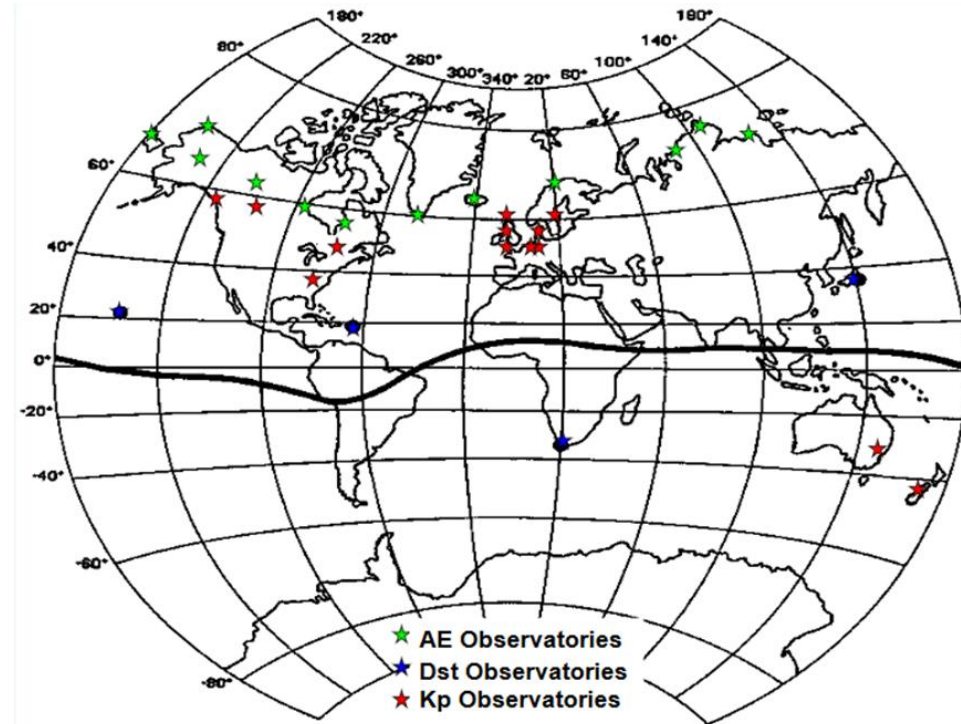


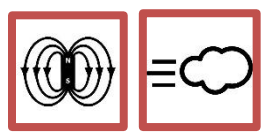
Kp	00	0+	1-	10	1+	2-	20	2+	3-	30	3+	4-	40	4+
ap	0	2	3	4	5	6	7	9	12	15	18	22	27	32
Kp	5-	50	5+	6-	60	6+	7-	70	7+	8-	80	8+	9-	90
ap	39	48	56	67	80	94	111	132	154	179	207	236	300	400



Geomagnetic indices

- Dst
 - Disturbance storm-time index
 - Severity of magnetic storms
 - Depression of the intensity of the H-component
 - Westward current
 - Related to changes in the ring current
 - Measured by 4 stations close to magnetic equator
 - But not too close...



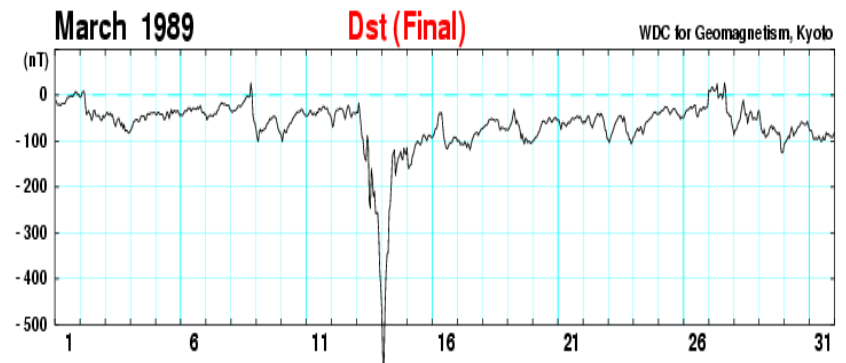


Geomagnetic indices

- Dst
 - Hourly measurements
 - Unit: nT
 - NOT a range index
 - Nomenclature
 - > -30 nT: Quiet
 - -30 - -50 nT: Weak storm
 - -50 - -100 nT: Moderate storm
 - -100 - -250 nT: Intense storm
 - < -250 nT: Extreme storm
- Most intense storms of SC24
 - 17 March 2015 (-234 nT)
 - 23 Jun 2015 (-198 nT)
- Most intense storms of SC25
 - **10-11 May 2024 (-406 nT)**
 - 10-11 October 2024 (-333 nT)
- Extreme storms
 - 30 October 2003: -383 nT
 - 14 March 1989: -589 nT
 - Carrington event: ~ -850 nT
 - 15 May 1921: ~ -907 nT

- Real-time monitoring at Kyoto, WDC (World Data Center)

– http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/presentmonth/index.html



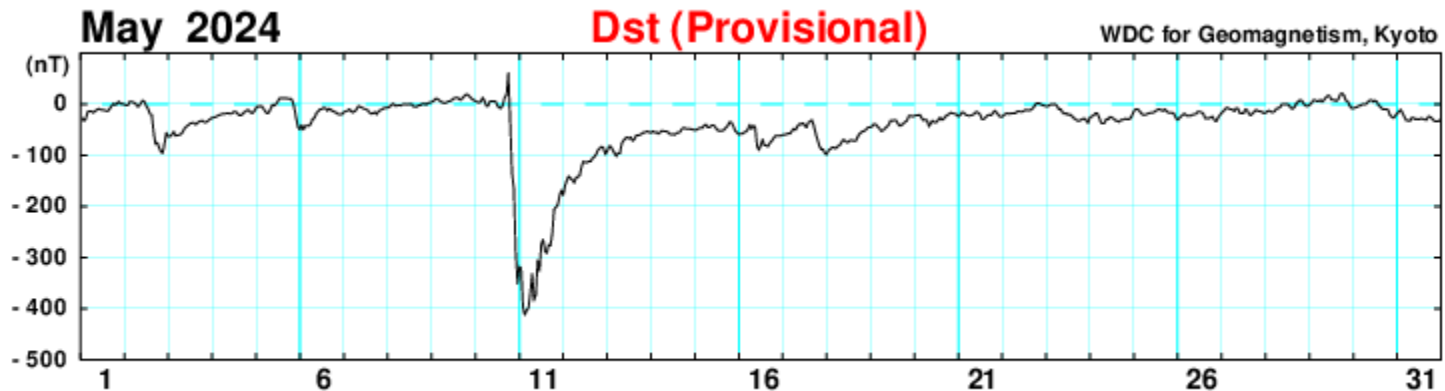
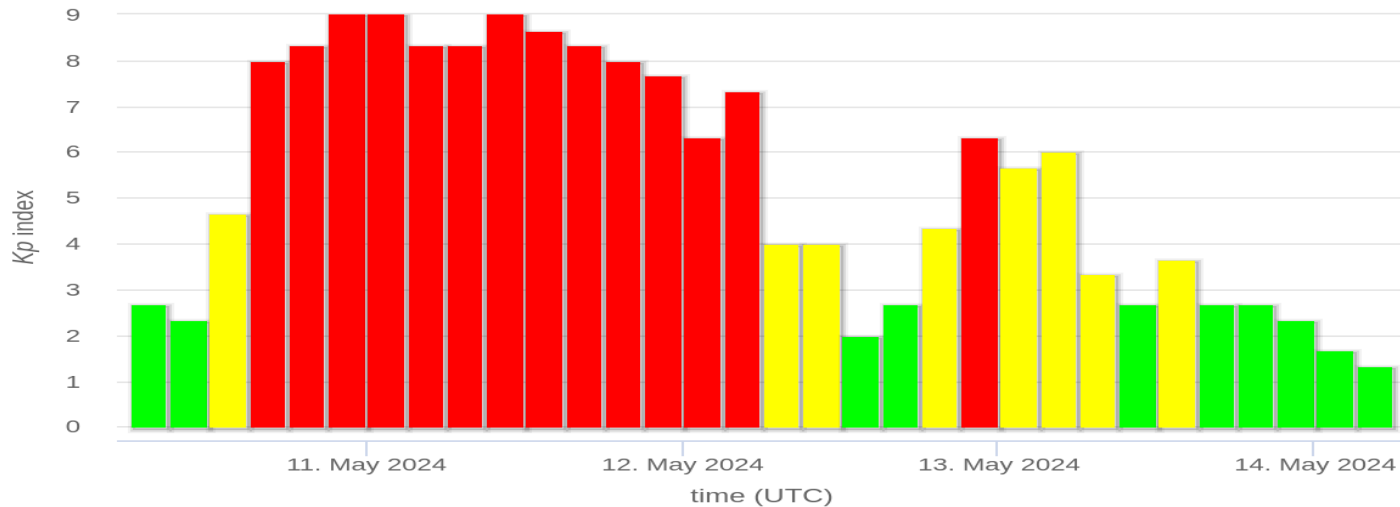


The great storm of 10-11 May 2024

(preliminary values)

Most recent geomagnetic storm with Kp index > 6

GFZ German Research Centre for Geosciences (CC BY 4.0)



:Issued: 2024 Mar 17 1231 UTC
:Product: documentation at <http://www.sidc.be/products/tot>
#-----#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
#-----#

SIDC URSIGRAM 40317
SIDC SOLAR BULLETIN 17 Mar 2024, 1231UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)

SOLAR PROTONS : Quiet
PREDICTIONS FOR 17 Mar 2024 10CM FLUX: 144 / AP: 007
PREDICTIONS FOR 18 Mar 2024 10CM FLUX: 146 / AP: 007
PREDICTIONS FOR 19 Mar 2024 10CM FLUX: 148 / AP: 007

Solar Active Regions and flaring: There are five active regions visible on the solar disk. They all have simple beta or alpha magnetic field configuration and produced minor C-class flaring. The main activity in the last 24 hours has been observed from active regions behind the east limb, that will rotate into view in the next hours. The strongest was an M3.5 flare peaking at 16:35 UTC on 16 March, from a region not yet visible, located behind the east limb. As these regions rotate into view, we expect more M-class and possible X-class flares in the next 24 hours.

Coronal mass ejections: There was a partial halo CME (angular width about 180 degrees) directed towards the south, first seen at 03:24 UTC by LASCO C2. This CME originates from a filament eruption in the southern hemisphere. Since the filament was located close to the disk center, an ICME may arrive to the Earth on 20-21 March (a better estimation will be given when more data become available).

Solar wind: Solar wind: The Earth is inside slow solar wind, with speeds close to 350 km/s and an interplanetary magnetic field around 5 nT. Similar conditions are expected for the next 24 hours.

Geomagnetism: Geomagnetic conditions were quiet both global and locally (NOAA_Kp up to 1 and K_BEL up to 1). Similar conditions can be expected for the next 24 hours.

Proton flux levels: The 10 MeV proton flux (measured by GOES-18) has come below the 10 pfu threshold, but remains elevated. It is expected that it will go back to low levels in the next 24 hours.

Electron fluxes at GEO: The greater than 2 MeV electron flux from GOES 16 was below the threshold level in the last 24 hours. It is expected to remain below the threshold during the next 24 hours. The 24h electron fluence was at normal level and is expected to remain so.

TODAY'S ESTIMATED ISN : 074, BASED ON 10 STATIONS.

SOLAR INDICES FOR 16 Mar 2024
WOLF NUMBER CATANIA : ///
10CM SOLAR FLUX : 144

AK CHAMBON LA FORET : 005
AK WINGST : 002
ESTIMATED AP : 002
ESTIMATED ISN : 058, BASED ON 23 STATIONS.

NOTICEABLE EVENTS SUMMARY

DAY	BEGIN	MAX	END	LOC	XRAY	OP	10CM	Catania/NOAA	RADIO_BURST_TYPES
16	1622	1635	1644	//////	M3.5	//////			
16	2127	2155	2211	//////	M1.1	//////			
END									



Geomagnetic activity

Geomagnetic networks

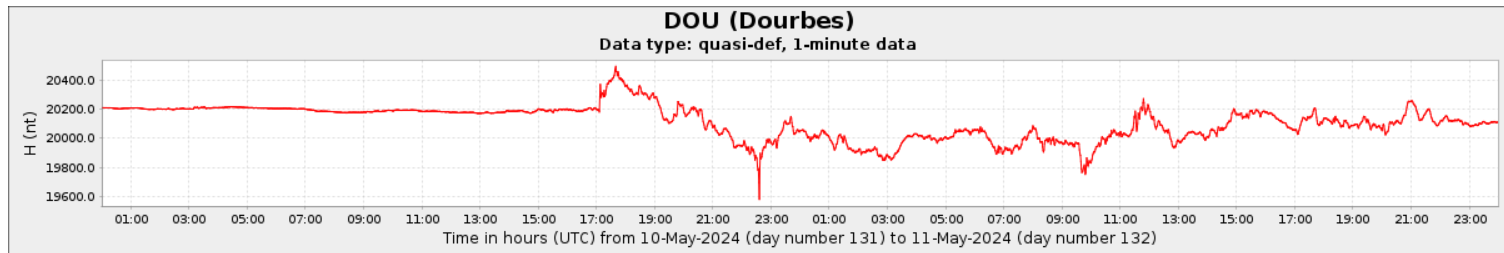
INTERMAGNET Data Viewer

For help using the form click on any of the descriptive text 'labels' to the left of each of the text input boxes.

Observatory: Data type:

Start date: Duration (days):

Sample period:



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Comments: [Mail the GIN manager](#)

Summary

- The magnetosphere
 - Has a drop-shape
 - Compressed at sunside, stretched at nightside
 - Contains several zones w/ particles of varying energies
 - Van Allen radiation belts,...
 - Protects us against high-energetic particles
- Geomagnetic storm
- The most often used geomagnetic indices are:
 - Kp, Ap, Dst

