

HF propagation and solar indices

ANATOMY OF THE SUN

Sunspots

Darker, cooler areas on the photosphere with concentrations of magnetic field

Prominence

Large structure, often many thousands of kilometres in extent

Granulation

Small, short-lived grainy features that cover the Sun, caused by thermal currents rising from below

Chromosphere

Layer above the photosphere, where the density of plasma drops dramatically

Photosphere

The visible 'surface' of the Sun

Transition region

Thin, irregular layer that separates the relatively cool chromosphere from the much hotter corona

Flare

Sudden release of energy in the form of radiation

Convective zone

Rapid heating of plasma creates currents of heated and cooled gas

Radiative zone

Energy created in the core diffuses slowly through the plasma

Core

Where the Sun generates its energy via thermonuclear reactions

Corona

The Sun's outer atmosphere, which extends millions of kilometres into outer space

Coronal mass ejection

Vast eruption of billions of tonnes of plasma and accompanying magnetic fields from the Sun's corona

Solar wind

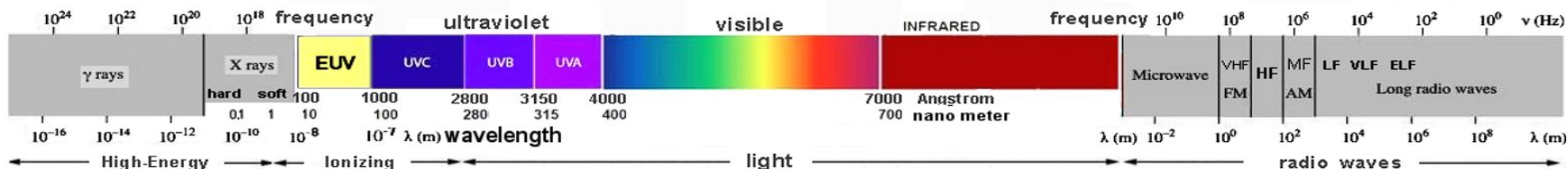
A continuous stream of charged particles released from the corona

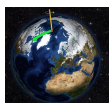
#SolarOrbiter #WeAreAllSolarOrbiters



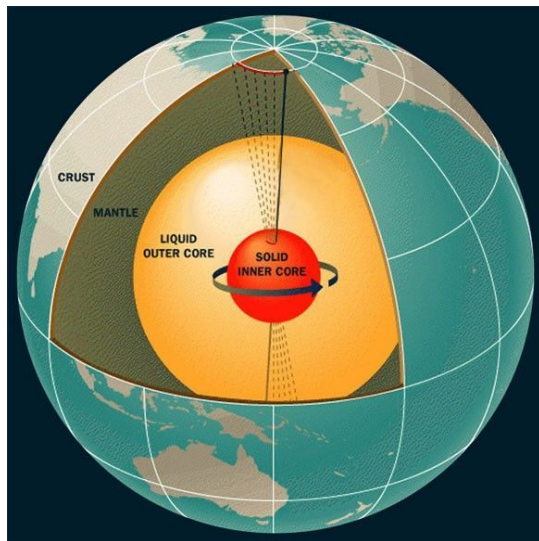
EUV = Extreme UV

The Electromagnetic Spectrum (wavelengths range from short to long)



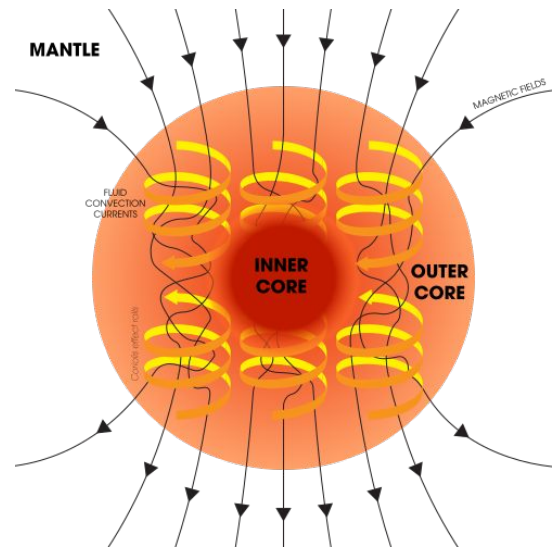


Earth



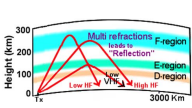
The Earth - A look inside

1. The crust - 19 to 30 miles
2. The mantle - Molten rock ~1,800 miles
3. The outer core - Molten iron and nickel ~1,400 miles
4. The inner core - Solid sphere of iron / nickel ~760. Inner core is about as hot as the Sun's surface.

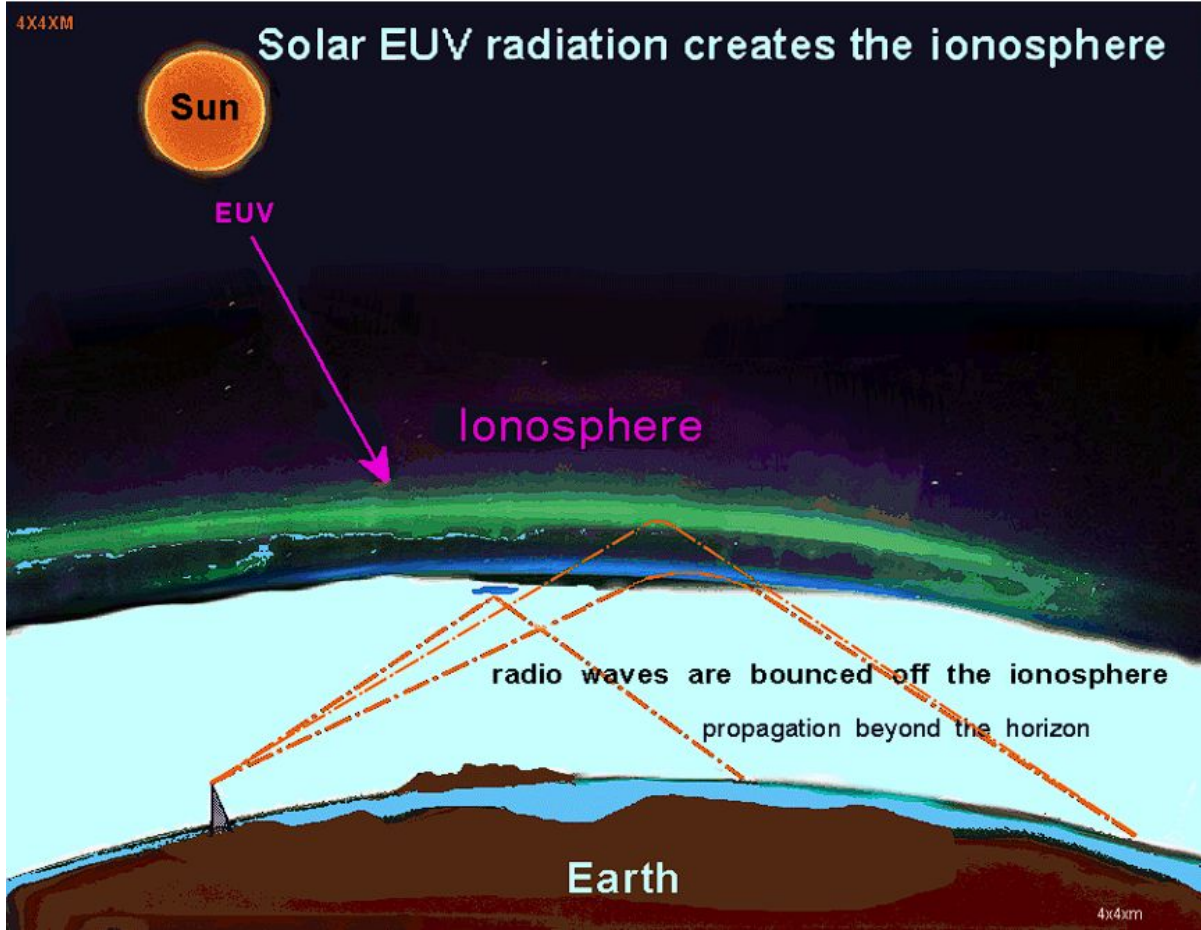


The Earth - A Geodynamo

1. Nearly all of Earth's magnetic field originates in the outer Core.
2. The molten magma swirls in whirlpools driven by Earth's rotation.
3. Electrical currents hundreds of miles wide flowing at thousands of mph maintains the magnetic field.
4. The magnetic field forms a dipole (north/south). The lines of flux travel in a continuous loop from North to South poles.

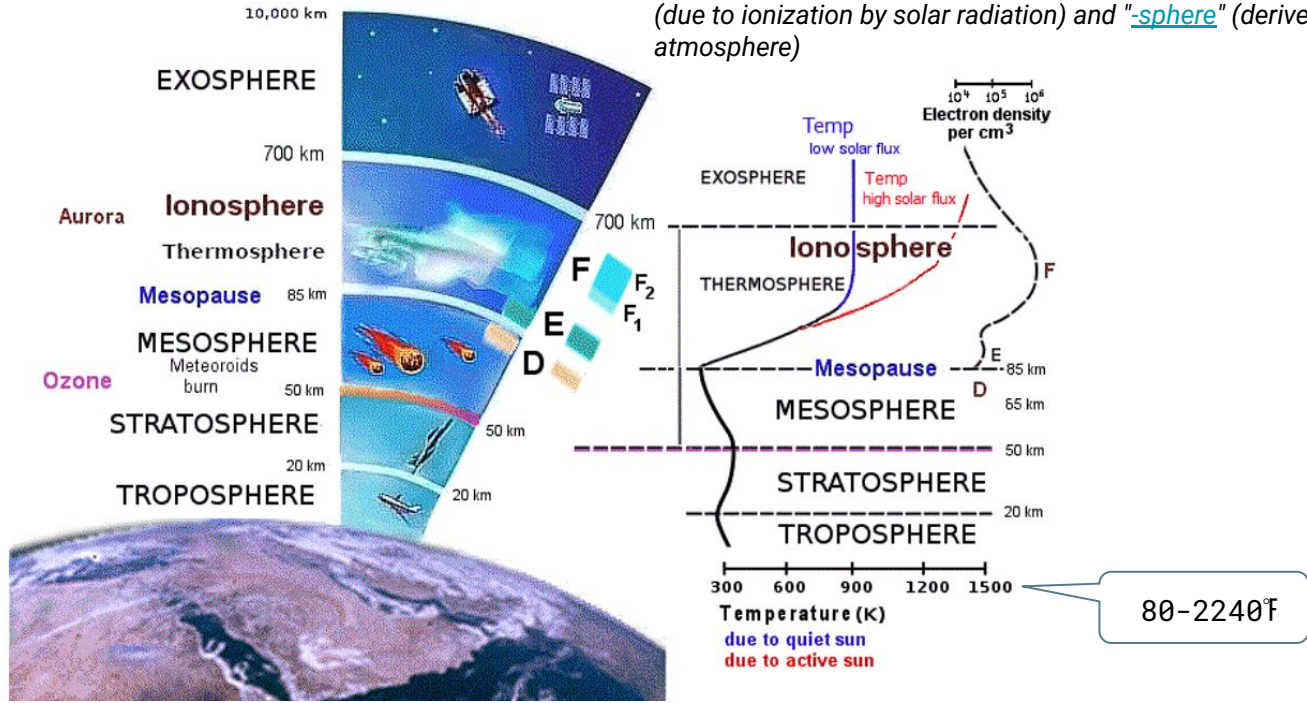
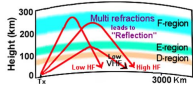


Propagation

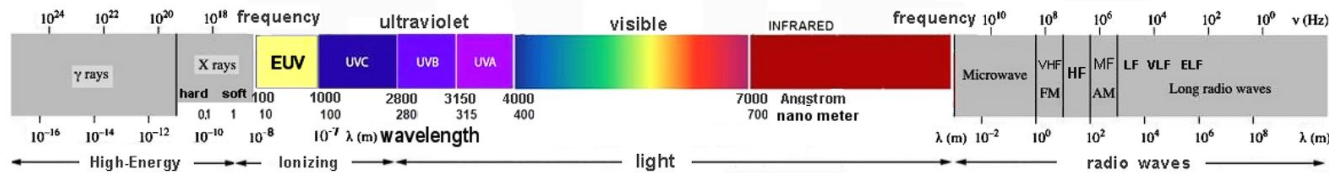


Propagation - Ionosphere

The term ionosphere was coined in 1926 by Scottish physicist [Robert A. Watson-Watt](#) to describe the region of Earth's upper atmosphere containing a high concentration of free electrons and ions. The name combines "ion" (due to ionization by solar radiation) and "-sphere" (derived from atmosphere)



The Electromagnetic Spectrum (wavelengths range from short to long)



Propagation - Ionization

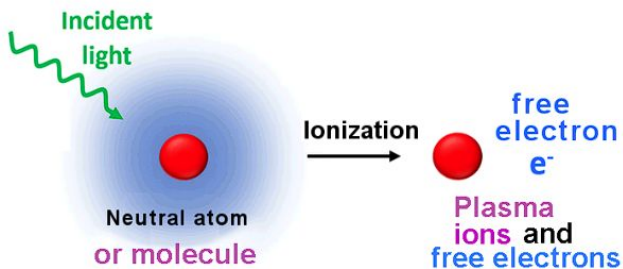
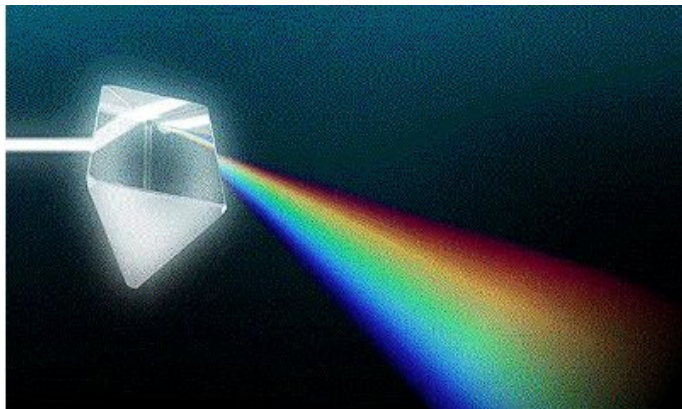
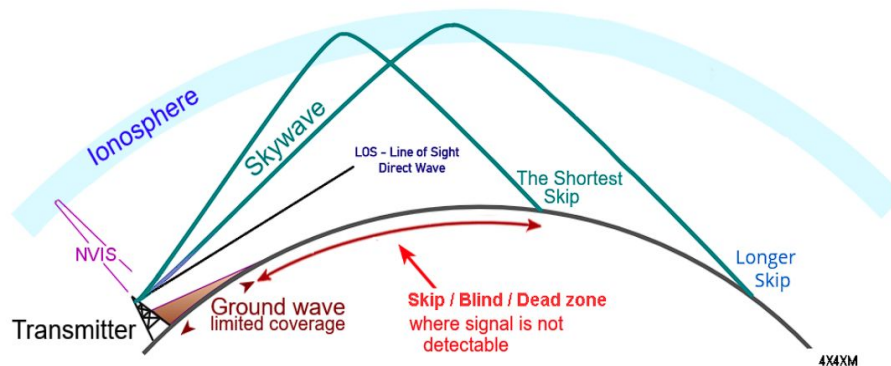


Figure 6.2: Ionization in the ionosphere generates plasma: a mixture of atoms, molecules, ions, and free electrons

The solar radiation generates a plasma which disperses and refracts (bends) radio waves. This results in several types of skywave signals (long/mid range), multi hop, NVIS, and gray line.

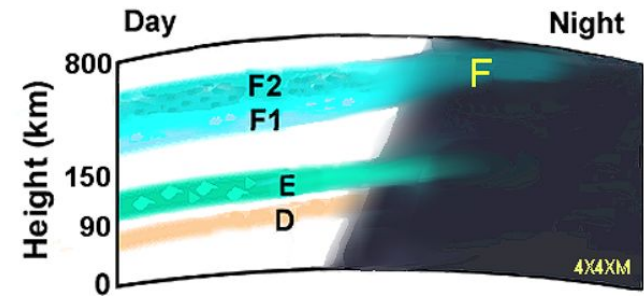


Refracted light waves through a prism



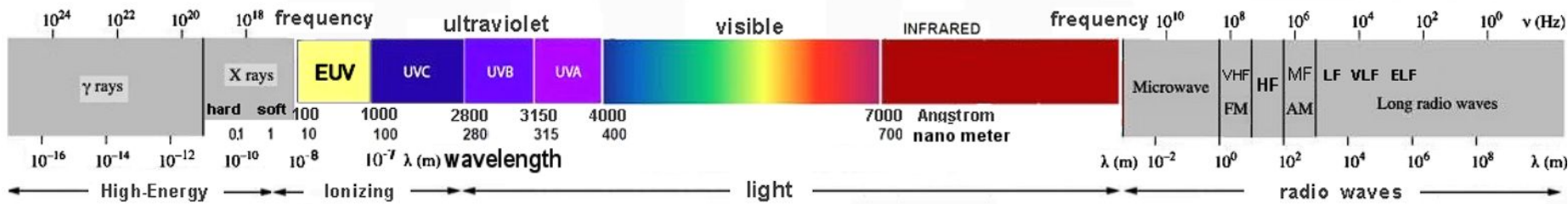
Refracted radio waves through the Ionosphere

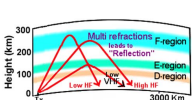
Propagation F&E Region



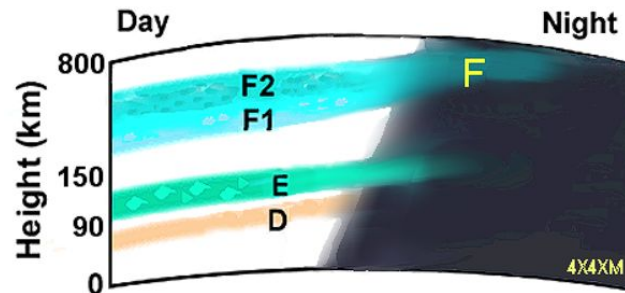
- The **F region**, located between 150 and 800 km above the Earth, enables **long-distance** HF communication in the **3.5 to 30 MHz** bands. This region consists of **ionized** \nearrow atomic oxygen (O^+) hydrogen (H^+) and helium (He^{++}) with the highest **free-electron density** up to 10^{12} electrons/m³ excited by the **solar EUV** \nearrow . It splits during the day into two sub-regions, F_1 and F_2 , which merge and slowly dissipate after sunset.
- The **E region**, located between 90 and 150 km above the Earth, dissipates a couple of hours after sunset. This region consists of ions such as O_2^+ , O^+ up to 10^{11} electrons/m³ excited by the **solar EUV**.

The Electromagnetic Spectrum (wavelengths range from short to long)





Propagation D Region



- The **D region**, located 50–90 km above ground, is active during the daytime and disappears at sunset.
- In this region, [solar UVC](#) at 121.6 nm excites nitric oxide ions (NO^+), up to 10^{10} electrons/ m^3 . This causes low HF (~3–10 MHz) to be [absorbed](#) during daylight hours, preventing frequencies lower than the [lowest usable frequency \(LUF\)](#) from reaching higher E and F regions ([Figure 7.9](#)).

Additionally, two D region phenomena may disturb "normal" propagation conditions

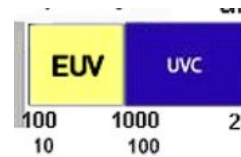
1. Intense bursts of X-rays from [intense solar flares](#) dramatically increase D region ionization, raising its electron density. This causes radio signals to be absorbed at increasingly higher frequencies—a phenomenon known as a [radio fadeout/blackout](#), which can persist from several minutes to a few hours.
2. Enhanced [solar wind](#) and [CMEs](#) may cause [Polar Cap Absorption \(PCA\)](#) events that can last up to 48 hours. HF radio blackouts caused by high-energy solar protons bombarding the polar ionosphere

PCA: High Energy protons impacting the polar ionosphere $>62^\circ$

SFI - Solar Flux Index

How it's Measured

- **Frequency:** Radio telescopes are tuned to receive emissions at 2.8 GHz (10.7 cm) wavelength.
- **Location:** The [Dominion Radio Astrophysical Observatory](#) (DRAO) in [Penticton](#), Canada, maintains this consistent, long-term record.
- **Units:** The measurement is in Solar Flux Units (SFU), where $1 \text{ sfu} = 10^{-22} \text{ Watts per square meter per Hertz (W/m}^2/\text{Hz)}$.
- **Purpose:** It acts as a proxy for the Sun's ultraviolet (UV) output, which directly affects the ionization level of Earth's upper atmosphere (ionosphere)



👉 Ionizing Radiation

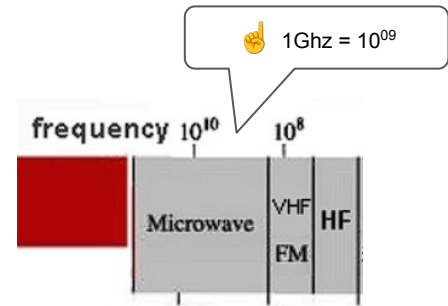
SFI - A Proxy View

The energy used to create the ionosphere is Extreme Ultraviolet radiation. Since the radiation does not reach the ground before the space age, scientists had two indirect markers to gauge the ionization levels of the F region. They are:

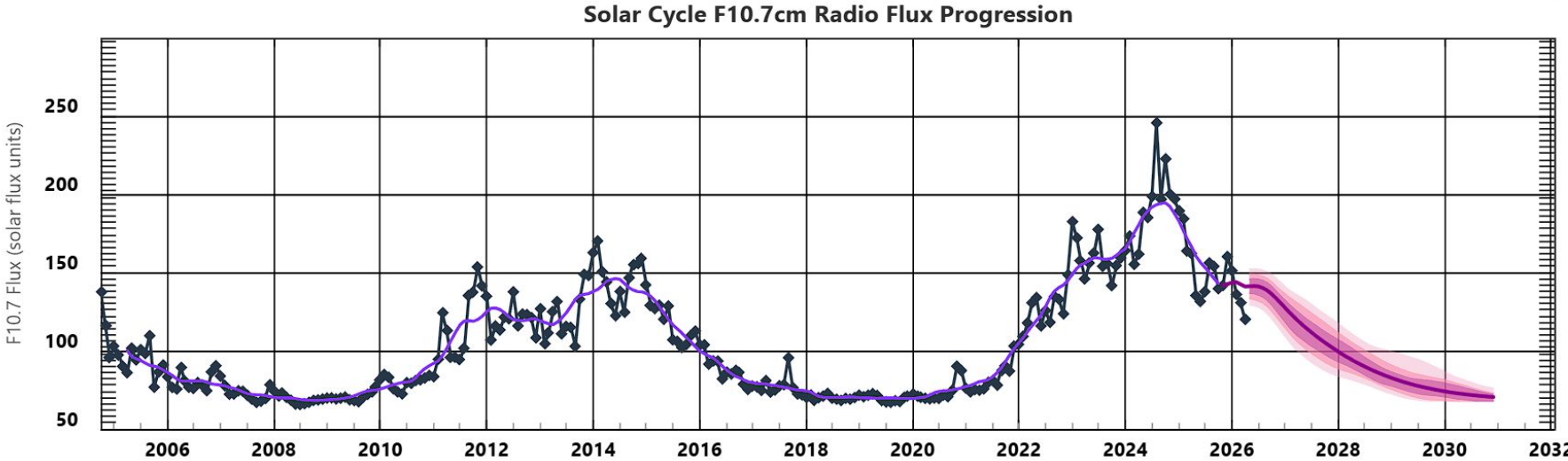
SFI - *Solar flux index* refers to the intensity of **solar radio emissions** at 10.7 cm (2.8 GHz).

SSN - The *Sunspot number* is a count of the number of **dark spots** seen on the sun. A higher SSN correlates to improved conditions on 20 meter and above HF bands.

SFI (sfu)	67	83	102	124	148	172	196	219	240	273	
HF Conditions	BAD		Low		Average		Good		Better		Best
MUF (MHz)	<12	<15	> 21		> 24		> 28		> 50		
SSN	0	25	50	75	100	125	150	175	200	250	



SFI & Sun Spots - A long term view



Kp Index

What is the Kp index?

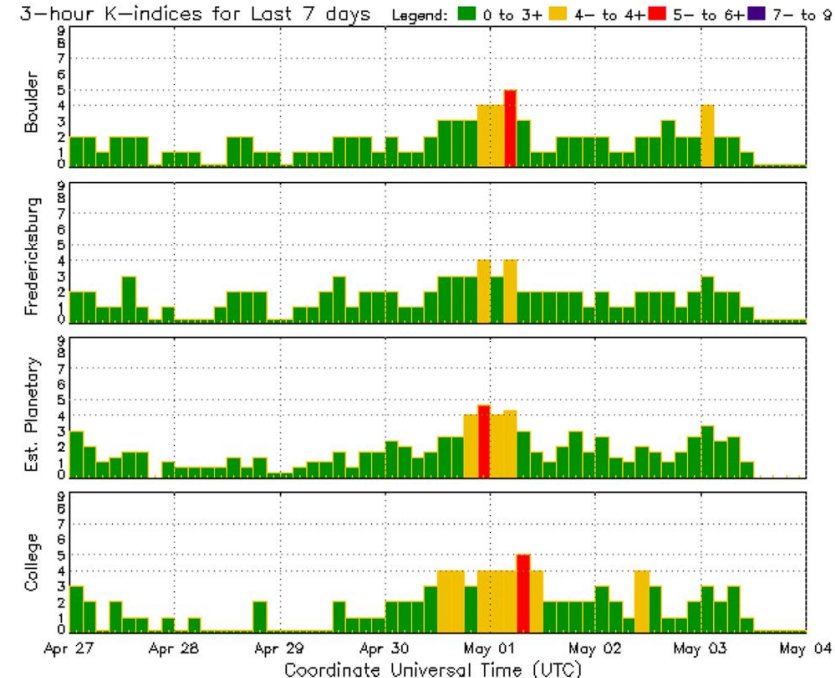
The geomagnetic three-hourly K_p index was introduced by J. Bartels in 1949 and is derived from the standardized K index (K_s) of 13 magnetic observatories. It is designed to measure solar particle radiation by its magnetic effects. It is a **proxy** for the energy input from the solar wind to Earth. The name K_p originates from "planetarische Kennziffer" (= planetary index).

The Kp Index is monitored by ground-based magnetic observatories recording the magnetic field components. The global K_p index is obtained as the mean value of the disturbance levels in the two horizontal field components, observed at 13 selected, subauroral stations. The stations are in Scotland, Canada, Alaska, Sweden, Denmark, England, Germany, Netherland, Australia, and New Zealand.

The K-index, and by extension the Planetary K-index, are used to characterize the magnitude of geomagnetic storms. K_p is an excellent indicator of disturbances in the Earth's magnetic field and is used to decide whether geomagnetic alerts and warnings need to be issued for users who are affected by these disturbances.

Kp index: 3 Hour Observation

Station K Indices



Updated 2026 May 3 1230

NOAA/SWPC Boulder, CO USA

Ap Index

What is the Ap index?

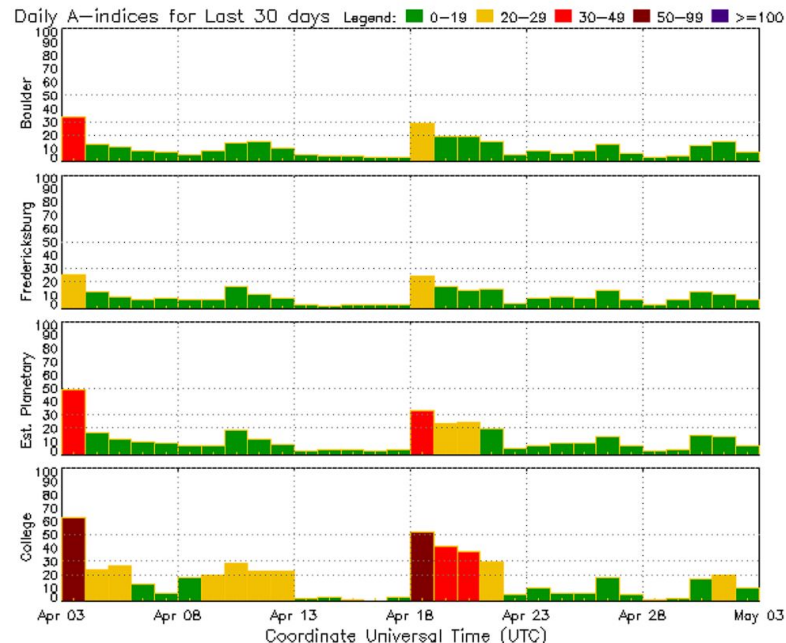
The Ap index is derived from the Kp index in a way that is analogous with the relationship between the station K-index and station A-index. Each individual, three-hourly Kp index is converted to an equivalent amplitude three-hourly a_{kp} index, and the average of eight, three-hourly a_{kp} indices is calculated to produce the 24 hour Ap index.

The relationship between Kp and Ap

The A-index was invented because there was a need to derive some kind of daily average level for geomagnetic activity. Because of the non-linear relationship of the K-scale to magnetometer fluctuations, it is not meaningful to take averages of a set of K indices. What is done instead is to convert each K back into a linear scale called the "equivalent three hourly range" a-index (note the lower case). Essentially Ap is used for a daily summary, while Kp is used for monitoring real-time activity.

Ap index: average of eight, three-hourly a_{kp}

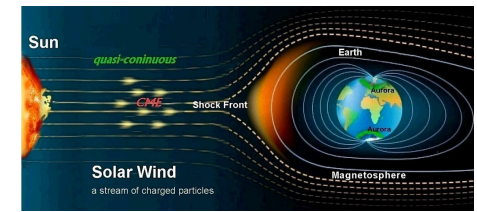
Station A Indices



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NOAA/SWPC Boulder, CO USA

Space Weather Scales



The National Oceanic and Atmospheric Administration (NOAA) introduced three Space Weather Scales (SWS) in 1999. The Scales are R, S, and G.

- **Radio Blackouts (R)** is a measure of x-ray flux from solar flares that corresponds to the strength of radio interference on the sunlit side of the Earth.
- **Solar Radiation Storms (S)** is a measure of energetic proton flux associated with the immensity of a solar radiation storm.
- **Geomagnetic Storms (G)** is a measure of global geomagnetic activity due to solar wind activity and coronal mass ejections.

Indices Scales - Geomagnetic, Solar, Radio

Minor	Moderate	Strong	Severe	Extreme
G 1	G 2	G 3	G 4	G 4

Minor	Moderate	Strong	Severe	Extreme
S 1	S 2	S 3	S 4	S 4

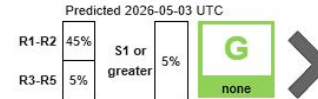
Minor	Moderate	Strong	Severe	Extreme
R 1	R 2	R 3	R 4	R 4

Indices Scales

SFI/SFU	Solar Activity	SSN	Solar Activity	A _p	Geomagnetic Activity	K _p	G	Geomagnetic-Storm
>=250	Extreme	>250	Best	>100	Severe Storm	9	5	Extreme
220-240	Better	220-250	Better	50-99	Major Storm	8	4	Severe
196-219	Good	150-175	Good	30-49	Minor Storm	7	3	Strong
148-172	Average	100-125	Average	16-29	Active	6	2	Moderate
102-124	Low	50-75	Low	8-15	Unsettled	5	1	Minor
67-83	Bad	0-25	Bad	0-7	Quiet	<5	0	Quiet

Example Solar Condition Dashboards

SPACE WEATHER CONDITIONS on NOAA Scales



Solar Wind Speed: 435 km/sec

Solar Wind Magnetic Fields: Bt 4 nT, Bz -3 nT

Noon 10.7cm Radio Flux: 159 sfu

13 Jan 2026 2001 GMT VHF Conditions

SFI	SN	49	Item	Status
A 18 K	1/Plntry		Aurora	Band Closed
X-Ray B9.9			6n EsEU	Band Closed
304A 118.4 @ SEM			4n EsEU	Band Closed
Ptn Flx 126			2n EsEU	Band Closed
Elc Flx 4260			2n EsNA	Band Closed
Aurora 5/n=1.99			EME Deg	Fair
Aur Lat 62.5°			MUF	
Bz -3.4 SW 539.9			MS	

Solar-Terrestrial Data
Provided by NONBH

HF Conditions	Current Solar Image
Band Day Night	
80n-40n Fair Good	
30n-20n Good Good	
17n-15n Fair Fair	
12n-10n Poor Poor	
Geomag Field VR QUIET	
Sig Noise Lvl S0-S1	
MUF US Boulder NoRpt	
Solar Flare Prb 31%	



Solar
NOAA.org / KQZG.com 5:10 PM

SFI 106 A 8 K 0.67

7.04 21.94 161 mi
FOF2 MUF HMF2

R 3 Strong S 2 Moderate G 4 Severe

Latest Observed

Flare/Storm Probabilities

R1-	40%
R2-	
R3-R5	5%
S1+	5%

Solar Conditions

Moderate	Very Quiet	Unsettled
120 SFI	1.33 K	13 A
0 250	0 10	0 400
Latest R0 S0 G0	24-Hour R0 S0 G0	Predicted R0 S0 G0
MUF 30.7 MHz	foF2 8.9 MHz	X-Ray C2.4 C1.4



NOAA SpaceWx Scale 0 - 5

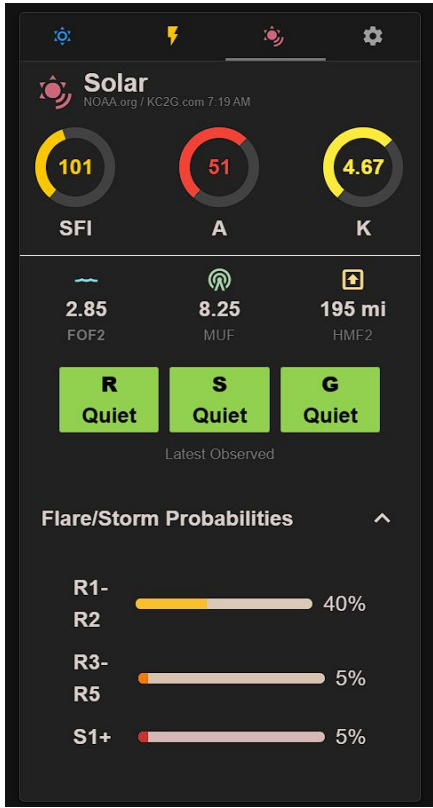
Radio blackout	0 0 0
Solar storm	0 0 0
Magnetic storm	0 0 0
Now D+1 D+2 D+3	

Az:241 E1:-20

Planetary Kp 1.3

R0@02:00 419m/s

Days -7 0 +2



References

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Paul Harden, NA5N - *Solar Activity & HF Propagation*

NOAA Space Weather Prediction Center - [NOAA](#)

Wiki - [Dominion Radio Astrophysical Observatory](#)

Wiki - https://en.wikipedia.org/wiki/Geomagnetic_storm