Sporadic E

and other RF Propagation Forms (PA00NEWS)

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Sporadic E propagation

Sporadic E or **E_s** is an unusual form of radio propagation using characteristics of the Earth's ionosphere. Whereas most forms of skywave propagation use the normal and cyclic ionization properties of the ionosphere's F region to refract (or "bend") radio signals back toward the Earth's surface, sporadic E propagation bounces signals off smaller "clouds" of unusually ionized atmospheric gas in the lower E region (located at altitudes of approx. 90 to 160 km). This occasionally allows for long-distance communication at VHF frequencies not usually well-suited to such communication.[1]

Communication distances of 800–2200 km can occur using a single E_s cloud. This variability in distance depends on a number of factors, including cloud height and density. MUF also varies widely, but most commonly falls in the 27–110 MHz range, which includes the FM broadcast band (87.5–108 MHz), Band I VHF television (American channels 2-6, Russian channels 1-3, and European channels 2-4, the latter no longer widely used in Western Europe), CB radio (27 MHz) and the amateur radio 10- and 6-meter bands. Strong events have allowed propagation at frequencies as high as 250 MHz.Wikipedia:Citation needed

As its name suggests, sporadic E is an abnormal event, not the usual condition, but can happen at almost any time; it does, however, display seasonal patterns. Sporadic E activity peaks predictably in the summertime in both hemispheres. In North America, the peak is most noticeable in mid-to-late June, trailing off through July and into August. A much smaller peak is seen around the winter solstice. Activity usually begins in mid-December in the southern hemisphere, with the days immediately after Christmas being the most active period.Wikipedia:Citation needed

On June 12, 2009, sporadic E allowed some television viewers in the eastern United States to see VHF analog TV stations from other states at great distances, in places and on TV channels where local stations had already done their permanent analog shutdown on the final day of the DTV transition in the United States. This was possible because VHF has been mostly avoided by digital TV stations, leaving the analog stations the last ones on the band. It is still possible (as of April, 2010) for many Americans to see Canadian and Mexican analog stations in this manner when sporadic-E occurs, until those countries do their own analog shutdowns over the following few years.

Characteristics

Television and FM signals received via Sporadic E can be extremely strong and range in strength over a short period from just detectable to overloading. Although polarisation shift can occur, single-hop Sporadic E signals tend to remain in the original transmitted polarisation. Long single-hop (900–1,500 miles or 1,400–2,400 kilometres) Sporadic E television signals tend to be more stable and relatively free of multipath images. Shorter-skip (400–800 miles or 640–1,290 kilometres) signals tend to be reflected from more than one part of the Sporadic E layer, resulting in multiple images and ghosting, with phase reversal at times. Picture degradation and signal-strength attenuation increases with each subsequent Sporadic E hop.

Sporadic E usually affects the lower VHF band I (TV channels 2 – 6) and band II (88 – 108 MHz FM broadcast band). The typical expected distances are about 600 to 1,400 miles (970 to 2,250 km). However, under exceptional circumstances, a highly ionized Es cloud can propagate band I VHF signals down to approximately 350 miles (560 km). When short-skip Es reception occurs, i.e., under 500 miles (800 km) in band I, there is a greater possibility that the ionized Es cloud will be capable of reflecting a signal at a much higher frequency – i.e., a VHF band 3 channel – since a sharp reflection angle (short skip) favours low frequencies, a shallower reflection angle from the same ionized cloud will favour a higher frequency.

At polar latitudes, Sporadic E can accompany auroras and associated disturbed magnetic conditions and is called Auroral-E.

No conclusive theory has yet been formulated as to the origin of Sporadic E. Attempts to connect the incidence of Sporadic E with the eleven-year Sunspot cycle have provided tentative correlations. There seems to be a positive correlation between sunspot maximum and Es activity in Europe. Conversely, there seems to be a negative correlation between maximum sunspot activity and Es activity in Australasia.

Equatorial E-skip

Equatorial E-skip is a regular daytime occurrence over the equatorial regions and is common in the temperate latitudes in late spring, early summer and, to a lesser degree, in early winter. For receiving stations located within +/− 10 degrees of the geomagnetic equator, equatorial E-skip can be expected on most days throughout the year, peaking around midday local time.

Notes

[1] amfmdx.net. Sporadic E Reference Page. http://www.amfmdx.net/fmdx/sporadic-e.html Accessed 3 July 2008.

Further reading

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- VHF PROPAGATION, A GUIDE FOR RADIO AMATEURS (Neubeck, West, CQ Publications)
- One account of the DTV transition/Es event on June 12, 2009 (http://www.tvdxexpo.com/)
- Sporadic E overview (http://www.radio-electronics.com/info/propagation/ionospheric/sporadic-e.php)

Radio propagation

Part of a series on

Antennas

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Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere.[2] As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.[3]

Radio propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the Sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems.

Radio propagation is also affected by several other factors determined by its path from point to point. This path can be a direct line of sight path or an over-the-horizon path aided by refraction in the ionosphere, which is a region between approximately 60 and 600 km.[4] Factors influencing ionospheric radio signal propagation can include sporadic-E, spread-F, solar flares, geomagnetic storms, ionospheric layer tilts, and solar proton events.

Radio waves at different frequencies propagate in different ways. At extra low frequencies (ELF) and very low frequencies the wavelength is very much larger than the separation between the earth's surface and the D layer of the ionosphere, so electromagnetic waves may propagate in this region as a waveguide. Indeed, for frequencies below 20 kHz, the wave propagates as a single waveguide mode with a horizontal magnetic field and vertical electric field.[5] The interaction of radio waves with the ionized regions of the atmosphere makes radio propagation more complex to predict and analyze than in free space. Ionospheric radio propagation has a strong connection to space weather. A sudden ionospheric disturbance or shortwave fadeout is observed when the x-rays associated with a solar flare ionize the ionospheric D-region.Wikipedia:Citation needed Enhanced ionization in that region increases the absorption of radio signals passing through it. During the strongest solar x-ray flares, complete absorption of virtually all ionospherically propagated radio signals in the sunlit hemisphere can occur.Wikipedia:Citation needed These solar flares can disrupt HF radio propagation and affect GPS accuracy.Wikipedia:Citation needed

Since radio propagation is not fully predictable, such services as emergency locator transmitters, in-flight communication with ocean-crossing aircraft, and some television broadcasting have been moved to communications satellites. A satellite link, though expensive, can offer highly predictable and stable line of sight coverage of a given area.

Free space propagation

In free space, all electromagnetic waves (radio, light, X-rays, etc.) obey the inverse-square law which states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from a point source[6] or:

$$\rho_P \propto \frac{1}{r^2}.$$

Doubling the distance from a transmitter means that the power density of the radiated wave at that new location is reduced to one-quarter of its previous value.

The power density per surface unit is proportional to the product of the electric and magnetic field strengths. Thus, doubling the propagation path distance from the transmitter reduces each of their received field strengths over a free-space path by one-half.

Modes

Radio frequencies and their primary mode of propagation

Band		Frequency	Wavelength	Propagation via
ELF	Extremely Low Frequency	3–30 Hz	10,000-100,000 km	
SLF	Super Low Frequency	30–300 Hz	10,000-1,000 km	
ULF	Ultra Low Frequency	0.3–3 kHz	1,000–100 km	
VLF	Very Low Frequency	3–30 kHz	100–10 km	Guided between the earth and the ionosphere.
LF	Low Frequency	30–300 kHz	10–1 km	Guided between the earth and the D layer of the ionosphere. Surface waves.
MF	Medium Frequency	300–3000 kHz	1000–100 m	Surface waves. E, F layer ionospheric refraction at night, when D layer absorption weakens.
HF	High Frequency (Short Wave)	3–30 MHz	100–10 m	E layer ionospheric refraction. F1, F2 layer ionospheric refraction.
VHF	Very High Frequency	30–300 MHz	10–1 m	Infrequent E ionospheric (E_s) refraction. Uncommonly F2 layer ionospheric refraction during high sunspot activity up to 50 MHz and rarely to 80 MHz. Generally direct wave. Sometimes tropospheric ducting.
UHF	Ultra High Frequency	300–3000 MHz	100–10 cm	Direct wave. Sometimes tropospheric ducting.
SHF	Super High Frequency	3–30 GHz	10–1 cm	Direct wave.
EHF	Extremely High Frequency	30–300 GHz	10–1 mm	Direct wave limited by absorption.
THF	Tremendously High frequency	0.3–3 THz	1–0.1 mm	

Surface modes (groundwave)

Main article: Surface wave

Lower frequencies (between 30 and 3,000 kHz) have the property of following the curvature of the earth via groundwave propagation in the majority of occurrences.

In this mode the radio wave propagates by interacting with the semi-conductive surface of the earth. The wave "clings" to the surface and thus follows the curvature of the earth. Vertical polarization is used to alleviate short circuiting the electric field through the conductivity of the ground. Since the ground is not a perfect electrical conductor, ground waves are attenuated rapidly as they follow the earth’s surface. Attenuation is proportional to the frequency making this mode mainly useful for LF and VLF frequencies (see also Earth-ionosphere waveguide).

Today LF and VLF are mostly used for time signals, and for military communications, especially one-way transmissions to ships and submarines, although radio amateurs have an allocation at 137 kHz in some parts of the world. Radio broadcasting using surface wave propagation uses the higher portion of the LF range in Europe, Africa and the Middle East.

Early commercial and professional radio services relied exclusively on long wave, low frequencies and ground-wave propagation. To prevent interference with these services, amateur and experimental transmitters were restricted to the higher (HF) frequencies, felt to be useless since their ground-wave range was limited. Upon discovery of the other propagation modes possible at medium wave and short wave frequencies, the advantages of HF for commercial and military purposes became apparent. Amateur experimentation was then confined only to authorized frequency segments in that range.

Direct modes (line-of-sight)

Line-of-sight is the direct propagation of radio waves between antennas that are visible to each other. This is probably the most common of the radio propagation modes at VHF and higher frequencies. Because radio signals can travel through many non-metallic objects, radio can be picked up through walls. This is still line-of-sight propagation. Examples would include propagation between a satellite and a ground antenna or reception of television signals from a local TV transmitter.

Ground plane reflection effects are an important factor in VHF line of sight propagation. The interference between the direct beam line-of-sight and the ground reflected beam often leads to an effective inverse-fourth-power ($1/\text{distance}^4$) law for ground-plane limited radiation. [Need reference to inverse-fourth-power law + ground plane. Drawings may clarify]

Ionospheric modes (skywave)

Main article: Skywave

Skywave propagation, also referred to as skip, is any of the modes that rely on refraction of radio waves in the ionosphere, which is made up of one or more ionized layers in the upper atmosphere. F2-layer is the most important ionospheric layer for long-distance, multiple-hop HF propagation, though F1, E, and D-layers also play significant roles. The D-layer, when present during sunlight periods, causes significant amount of signal loss, as does the E-layer whose maximum usable frequency can rise to 4 MHz and above and thus block higher frequency signals from reaching the F2-layer. The layers, or more appropriately "regions", are directly affected by the sun on a daily diurnal cycle, a seasonal cycle and the 11-year sunspot cycle and determine the utility of these modes. During solar maxima, or sunspot highs and peaks, the whole HF range up to 30 MHz can be used usually around the clock and F2 propagation up to 50 MHz is observed frequently depending upon daily solar flux 10.7cm radiation values. During solar minima, or minimum sunspot counts down to zero, propagation of frequencies above 15 MHz is generally unavailable.

Although the claim is commonly made that two-way HF propagation along a given path is reciprocal, that is, if the signal from location A reaches location B at a good strength, the signal from location B will be similar at station A because the same path is traversed in both directions. However, the ionosphere is far too complex and constantly changing to support the reciprocity theorem. The path is never exactly the same in both directions.[7] In brief, conditions at the two terminii of a path generally cause dissimilar polarization shifts, dissimilar splits into ordinary rays and extraordinary or *Pedersen rays* which are erratic and impossibly identical or similar due to variations in ionization density, shifting zenith angles, effects of the earth's magnetic DIPOLE contours, antenna radiation patterns, ground conditions and other variables.

Forecasting of skywave modes is of considerable interest to amateur radio operators and commercial marine and aircraft communications, and also to shortwave broadcasters. Real-time propagation can be assessed by listening for transmissions from specific beacon transmitters.

Meteor scattering

Meteor scattering relies on reflecting radio waves off the intensely ionized columns of air generated by meteors. While this mode is very short duration, often only from a fraction of second to couple of seconds per event, digital Meteor burst communications allows remote stations to communicate to a station that may be hundreds of miles up to over 1,000 miles (1,600 km) away, without the expense required for a satellite link. This mode is most generally useful on VHF frequencies between 30 and 250 MHz.

Auroral backscatter

Intense columns of Auroral ionization at 100 km altitudes within the auroral oval backscatter radio waves, perhaps most notably on HF and VHF. Backscatter is angle-sensitive—incident ray vs. magnetic field line of the column must be very close to right-angle. Random motions of electrons spiraling around the field lines create a Doppler-spread that broadens the spectra of the emission to more or less noise-like—depending on how high radio frequency is used. The radio-auroras are observed mostly at high latitudes and rarely extend down to middle latitudes. The occurrence of radio-auroras depends on solar activity (flares, coronal holes, CMEs) and annually the events are more numerous during solar cycle maxima. Radio aurora includes the so-called afternoon radio aurora which produces stronger but more distorted signals and after the Harang-minima, the late-night radio aurora (sub-storming phase) returns with variable signal strength and lesser doppler spread. The propagation range for this predominantly back-scatter mode extends up to about 2000 km in east-west plane, but strongest signals are observed most frequently from the north at nearby sites on same latitudes.

Rarely, a strong radio-aurora is followed by Auroral-E, which resembles both propagation types in some ways.

Sporadic-E propagation

Main article: Sporadic E propagation

Sporadic E (Es) propagation can be observed on HF and VHF bands. It must not be confused with ordinary HF E-layer propagation. Sporadic-E at mid-latitudes occurs mostly during summer season, from May to August in the northern hemisphere and from November to February in the southern hemisphere. There is no single cause for this mysterious propagation mode. The reflection takes place in a thin sheet of ionisation around 90 km height. The ionisation patches drift westwards at speeds of few hundred km per hour. There is a weak periodicity noted during the season and typically Es is observed on 1 to 3 successive days and remains absent for a few days to reoccur again. Es do not occur during small hours; the events usually begin at dawn, and there is a peak in the afternoon and a second peak in the evening.[8] Es propagation is usually gone by local midnight.

Observation of radio propagation beacons operating around 28.2 MHz, 50 MHz and 70 MHz, indicates that maximum observed frequency (MOF) for Es is found to be lurking around 30 MHz on most days during the summer season, but sometimes MOF may shoot up to 100 MHz or even more in ten minutes to decline slowly during the next few hours. The peak-phase includes oscillation of MOF with periodicity of approximately 5...10 minutes. The propagation range for Es single-hop is typically 1000 to 2000 km, but with multi-hop, double range is observed. The signals are very strong but also with slow deep fading.

Tropospheric modes

Tropospheric scattering

At VHF and higher frequencies, small variations (turbulence) in the density of the atmosphere at a height of around 6 miles (10 km) can scatter some of the normally line-of-sight beam of radio frequency energy back toward the ground, allowing over-the-horizon communication between stations as far as 500 miles (800 km) apart. The military developed the White Alice Communications System covering all of Alaska, using this tropospheric scattering principle.

Tropospheric ducting

Main article: Tropospheric ducting

Sudden changes in the atmosphere's vertical moisture content and temperature profiles can on random occasions make microwave and UHF & VHF signals propagate hundreds of kilometers up to about 2,000 kilometers (1,300 mi)—and for ducting mode even farther—beyond the normal radio-horizon. The inversion layer is mostly observed over high pressure regions, but there are several tropospheric weather conditions which create these randomly occurring propagation modes. Inversion layer's altitude for non-ducting is typically found between 100 meters (300 ft) to about 1 kilometer (3,000 ft) and for ducting about 500 meters to 3 kilometers (1,600 to 10,000 ft), and the duration of the events are typically from several hours up to several days. Higher frequencies experience the most dramatic increase of signal strengths, while on low-VHF and HF the effect is negligible. Propagation path attenuation may be below free-space loss. Some of the lesser inversion types related to warm ground and cooler air moisture content occur regularly at certain times of the year and time of day. A typical example could be the late summer, early morning tropospheric enhancements that bring in signals from distances up to few hundred kilometers for a couple of hours, until undone by the Sun's warming effect.

Tropospheric delay

This is a source of error in radio ranging techniques, such as the Global Positioning System (GPS).[9] See also the page of GPS meteorology.

Rain scattering

Rain scattering is purely a microwave propagation mode and is best observed around 10 GHz, but extends down to a few gigahertz—the limit being the size of the scattering particle size vs. wavelength. This mode scatters signals mostly forwards and backwards when using horizontal polarization and side-scattering with vertical polarization. Forward-scattering typically yields propagation ranges of 800 km. Scattering from snowflakes and ice pellets also occurs, but scattering from ice without watery surface is less effective. The most common application for this phenomenon is microwave rain radar, but rain scatter propagation can be a nuisance causing unwanted signals to intermittently propagate where they are not anticipated or desired. Similar reflections may also occur from insects though at lower altitudes and shorter range. Rain also causes attenuation of point-to-point and satellite microwave links. Attenuation values up to 30 dB have been observed on 30 GHz during heavy tropical rain.

Airplane scattering

Airplane scattering (or most often reflection) is observed on VHF through microwaves and, besides back-scattering, yields momentary propagation up to 500 km even in mountainous terrain. The most common back-scatter applications are air-traffic radar, bistatic forward-scatter guided-missile and airplane-detecting trip-wire radar, and the US space radar.

Lightning scattering

Lightning scattering has sometimes been observed on VHF and UHF over distances of about 500 km. The hot lightning channel scatters radio-waves for a fraction of a second. The RF noise burst from the lightning makes the initial part of the open channel unusable and the ionization disappears quickly because of recombination at low altitude and high atmospheric pressure. Although the hot lightning channel is briefly observable with microwave radar, no practical use for this mode has been found in communications.

Other effects

Diffraction

Knife-Edge diffraction is the propagation mode where radio waves are bent around sharp edges. For example, this mode is used to send radio signals over a mountain range when a line-of-sight path is not available. However, the angle cannot be too sharp or the signal will not diffract. The diffraction mode requires increased signal strength, so higher power or better antennas will be needed than for an equivalent line-of-sight path.

Diffraction depends on the relationship between the wavelength and the size of the obstacle. In other words, the size of the obstacle in wavelengths. Lower frequencies diffract around large smooth obstacles such as hills more easily. For example, in many cases where VHF (or higher frequency) communication is not possible due to shadowing by a hill, it is still possible to communicate using the upper part of the HF band where the surface wave is of little use.

Diffraction phenomena by small obstacles are also important at high frequencies. Signals for urban cellular telephony tend to be dominated by ground-plane effects as they travel over the rooftops of the urban environment. They then diffract over roof edges into the street, where multipath propagation, absorption and diffraction phenomena dominate.

Absorption

Low-frequency radio waves travel easily through brick and stone and VLF even penetrates sea-water. As the frequency rises, absorption effects become more important. At microwave or higher frequencies, absorption by molecular resonances in the atmosphere (mostly from water, H_2O and oxygen, O_2) is a major factor in radio propagation. For example, in the 58–60 GHz band, there is a major absorption peak which makes this band useless for long-distance use. This phenomenon was first discovered during radar research in World War II. Above about 400 GHz, the Earth's atmosphere blocks most of the spectrum while still passing some - up to UV light, which is blocked by ozone - but visible light and some of the near-infrared is transmitted. Heavy rain and falling snow also affect microwave absorption.

Measuring HF propagation

HF propagation conditions can be simulated using radio propagation models, such as the Voice of America Coverage Analysis Program, and realtime measurements can be done using chirp transmitters. For radio amateurs the WSPR mode provides maps with real time propagation conditions between a network of transmitters and receivers.[10] Even without special beacons the realtime propagation conditions can be measured: a worldwide network of receivers decodes morse code signals on amateur radio frequencies in realtime and provides sophisticated search functions and propagation maps for every station received.[11]

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[3] Demetrius T Paris and F. Kenneth Hurd, *Basic Electromagnetic Theory*, McGraw Hill, New York 1969 ISBN 0-07-048470-8, Chapter 8
[4] Radiowave propagation, edited by M.Hall and L.Barclay, page 2, published by Peter Peregrinus Ltd., (1989), ISBN 0-86341-156-8
[5] Radiowave propagation, edited by M.Hall and L.Barclay, published by Peter Peregrinus Ltd., page 3, (1989), ISBN 0-86341-156-8
[6] Westman *Reference data* page 26-19
[7] G.W. Hull, "Nonreciprocal characteristics of a 1500km HF Ionospheric Path," *Proceedings of the IEEE*, 55, March 1967, pp. 426-427; "Origin of non-reciprocity on high-frequency ionospheric paths," *Nature*, pp. 483-484, and cited references.
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[10] WSPR Propagation Conditions Map: http://wsprnet.org/drupal/wsprnet/map
[11] Network of CW Signal Decoders for Realtime Analysis: http://www.reversebeacon.net/

Further reading

- Lucien Boithais: *Radio Wave Propagation*. McGraw-Hill Book Company, New York. 1987. ISBN 0-07-006433-4
- Karl Rawer:*Wave Propagatiom im the Ionosphere*.Kluwer Acad.Publ.,Dordrecht 1993. ISBN 0-7923-0775-5
- H. Ward Silver and Mark J. Wilson, (eds), "Propagation of Radio Signals" (Ch. 19, by Emil Pocock), in *The ARRL Handbook for Radio Communications (88th edition, 2010), ARRL, Newington CT USA ISBN 0-87259-095-X*

External links

- Solar widget (http://rigreference.com/solar) Propagation widget based on NOAA data. Also available as WordPress plugin.
- ARRL Propagation Page (http://www.arrl.org/tis/info/propagation.html) The American Radio Relay League page on radio propagation.
- HF Radio and Ionospheric Prediction Service - Australia (http://www.ips.gov.au/HF_Systems/)
- NASA Space Weather Action Center (http://sunearthday.nasa.gov/swac/data.php)
- HF Propagation Tutorial by the late NM7M (http://www.astrosurf.com/luxorion/qsl-hf-tutorial-nm7m.htm)
- Space Weather and Radio Propagation Resource Center (http://sunspotwatch.com) Live data and images of space weather and radio propagation.
- Solar Terrestrial Dispatch (http://www.spacew.com/)
- Online Propagation Tools, HF Solar Data, and HF Propagation Tutorials (http://www.hamqsl.com/solar.html)
- DXing.info - Propagation links (http://www.dxing.info/propagation)
- HF Radio Propagation Software for Firefox - Propfire (http://www.n0hr.com/Propfire.htm) Firefox plug-in for monitoring propagation, website utility to display HF propagation status, and article on understanding HF radio propagation forecasting
- The Basics of Radio Wave Propagation (http://ecjones.org/propag.html) A resource by Edwin C. Jones (AE4TM), MD, PhD, Department of Physics and Astronomy, University of Tennessee.
- Dynamic Radio Propagation Data (http://dx.qsl.net/propagation/propagation.html) Constantly updated radio propagation data pulled from various sources.
- Solar Cycle 24 prediction and MF/HF/6M radiowave propagation forecast webpage (www.solarcycle24.org) (http://www.solarcycle24.org/)
- 160 Meter (Medium Frequency) Radiowave Propagation Theory Notes webpage (www.wcflunatall.com/nz4o5.htm) (http://www.wcflunatall.com/nz4o5.htm/)

- Unusual HF Propagation Phenomena. 13 Apr 2009 (http://www.qslnet.de/member/la3za/prop/) Includes useful recordings each type. Retrieved 9 Oct 2009.
- Overview of radio propagation modes (http://www.radio-electronics.com/info/propagation/radio-propagation/radio-propagation-overview-tutorial.php)
- Propagation: Es & Thunderstorms (http://lists.contesting.com/archives//html/Propagation/2005-04/msg00075.html) by Thomas F. Giella, NZ4O, ex KN4LF.

The following external references provide practical examples of radio propagation concepts as demonstrated using software built on the VOACAP model.

- Online MOF/LOF HF Propagation Prediction Tool (http://www.hamqsl.com/solar1.html#moflof)
- High Frequency radio propagation de-mystified. (http://hfradio.org/ace-hf/ace-hf-demystified.html)
- Is High Frequency radio propagation reciprocal? (http://hfradio.org/ace-hf/ace-hf-reciprocal.html)
- How does noise affect radio signals? (http://hfradio.org/ace-hf/ace-hf-noise.html)

The following external link is designed for use by cell phones and mobile devices that can display content using Wireless Markup Language and the Wireless Application Protocol:

- WAP/WML Space Weather and Radio Propagation Resources (http://wap.hfradio.org/) Space weather and radio propagation resources.

Tropospheric propagation

Tropospheric propagation describes electromagnetic propagation in relation to the troposphere.

The service area from a television (TV) or frequency modulated (FM) radio transmitter extends to just beyond the optical horizon, at which point signals start to rapidly reduce in strength. Viewers living in such a "deep fringe" reception area will notice that during certain conditions, weak signals normally masked by noise increase in signal strength to allow quality reception. Such conditions are related to the current state of the troposphere.

Tropospheric propagated signals travel in the part of the atmosphere adjacent to the surface and extending to some 25,000 feet (7,620 m). Such signals are thus directly affected by weather conditions extending over some hundreds of miles. During very settled, warm anticyclonic weather (i.e., high pressure), usually weak signals from distant transmitters improve in strength. Another symptom during such conditions may be interference to the local transmitter resulting in co-channel interference, usually horizontal lines or an extra floating picture with analog broadcasts and break-up with digital broadcasts. A settled high-pressure system gives the characteristic conditions for enhanced tropospheric propagation, in particular favouring signals which travel along the prevailing isobar pattern (rather than across it). Such weather conditions can occur at any time, but generally the summer and autumn months are the best periods. In certain favourable locations, enhanced tropospheric propagation may enable reception of ultra high frequency (UHF) TV signals up to 1,000 miles (1,600 km) or more.

The observable characteristics of such high-pressure systems are usually clear, cloudless days with little or no wind. At sunset the upper air cools, as does the surface temperature, but at different rates. This produces a boundary or temperature gradient, which allows an inversion level to form – a similar effect occurs at sunrise. The inversion is capable of allowing very high frequency (VHF) and UHF signal propagation well beyond the normal radio horizon distance.

The inversion effectively reduces sky wave radiation from a transmitter – normally VHF and UHF signals travel on into space when they reach the horizon, the refractive index of the ionosphere preventing signal return. With temperature inversion, however, the signal is to a large extent refracted over the horizon rather than continuing along a direct path into outer space.

Fog also produces good tropospheric results, again due to inversion effects. Fog occurs during high-pressure weather, and if such conditions result in a large belt of fog with clear sky above, there will be heating of the upper fog level and thus an inversion. This situation often arises towards night fall, continues overnight and clears with the sunrise over a period of around 4 – 5 hours.

Tropospheric ducting

Tropospheric ducting is a type of radio propagation that tends to happen during periods of stable, anticyclonic weather. In this propagation method, when the signal encounters a rise in temperature in the atmosphere instead of the normal decrease (known as a temperature inversion), the higher refractive index of the atmosphere there will cause the signal to be bent. Tropospheric ducting affects all frequencies, and signals enhanced this way tend to travel up to 800 miles (1,300 km) (though some people have received "tropo" beyond 1,000 miles / 1,600 km), while with tropospheric-bending, stable signals with good signal strength from 500+ miles (800+ km) away are not common when the HA JA JA index of the atmosphere is fairly high.

Tropospheric ducting of UHF television signals is relatively common during the summer and autumn months, and is the result of change in the refractive index of the atmosphere at the boundary between air masses of different temperatures and humidities. Using an analogy, it can be said that the denser air at ground level slows the wave front a little more than does the rare upper air, imparting a downward curve to the wave travel.

Ducting can occur on a very large scale when a large mass of cold air is overrun by warm air. This is termed a temperature inversion, and the boundary between the two air masses may extend for 1,000 miles (1,600 km) or more along a stationary weather front.

Temperature inversions occur most frequently along coastal areas bordering large bodies of water. This is the result of natural onshore movement of cool, humid air shortly after sunset when the ground air cools more quickly than the upper air layers. The same action may take place in the morning when the rising sun warms the upper layers.

Even though tropospheric ducting has been occasionally observed down to 40 MHz, the signal levels are usually very weak. Higher frequencies above 90 MHz are generally more favourably propagated.

High mountainous areas and undulating terrain between the transmitter and receiver can form an effective barrier to tropospheric signals. Ideally, a relatively flat land path between the transmitter and receiver is ideal for tropospheric ducting. Sea paths also tend to produce superior results.

In certain parts of the world, notably the Mediterranean Sea and the Persian Gulf, tropospheric ducting conditions can become established for many months of the year to the extent that viewers regularly receive quality reception of signals over distances of 1,000 miles (1,600 km). Such conditions are normally optimum during very hot settled summer weather.

Tropospheric ducting over water, particularly between California and Hawaii, Brazil and Africa, Australia and New Zealand, Australia and Indonesia, Strait of Florida, and Bahrain and Pakistan, has produced VHF/UHF reception ranging from 1000 to 3,000 miles (1,600 – 4,800 km). A US listening post was built in Ethiopia to exploit a common ducting of signals from southern Russia.

Tropospheric signals exhibit a slow cycle of fading and will occasionally produce signals sufficiently strong for noise-free stereo, reception of Radio Data System(RDS) data, and solid locks of HD Radio streams on FM or noise-free, color TV pictures.

Virtually all long-distance reception of digital television occurs by tropospheric ducting (due to most, but not all, DTV stations broadcasting in the UHF band).

Notable tropospheric DX receptions

- On October 18, 1975, Rijn Muntjewerff, the Netherlands, received UHF channel E34 Pajala, Sweden, at a distance of 1,150 miles (1,851 km).
- On June 13, 1989, Shel Remington, Keaau, Hawaii, received several 88-108 MHz FM signals from Tijuana, Mexico, at a distance of 2,536 miles (4,081 km).[1]
- Throughout the 1990s, Fernando Garcia, located at what could be considered an ideal tropospheric DX location near Monterrey, Mexico, received numerous 1,000+ mile (1,600+ km) stations via tropospheric propagation, both over the Gulf of Mexico and past land. Among his receptions are WGNT-27 from Portsmouth, Virginia, at a distance of 1,608 miles (2,588 km) and low-power (LPTV) station W38BB from Raleigh, North Carolina, at a distance of 1,460 miles (2,350 km)[2]
- On June 24, 2001, a Romanian engineer Ioan Albesteanu received Russian ORT television on channel 31 from the Babadag hills in the Russian city Назрань, Nazran. The reception was made at a distance of 1,290 kilometres (802 mi).[3]
- On May 11, 2003, Jeff Kruszka, living in south Louisiana, received a few UHF DTV signals from 800+ miles. The longest of these was WNCN-DT, channel 55, Goldsboro, North Carolina, at a distance of 835 miles (1,344 km) (at the time, the record for UHF DTV).[4]
- On the late evening of June 19, 2007 and into the early morning hours of June 20, 2007, three DXers in eastern Massachusetts, Jeff Lehmann, Keith McGinnis, and Roy Barstow, received FM signals from southern Florida via tropo. All three logged WEAT 104.3 West Palm Beach, Florida, and WRMF 97.9 Palm Beach, Florida, at distances of around 1,200 miles (1,931 km), and Barstow logged WHDR 93.1 Miami, Florida, at a distance of 1,210 miles (1,947 km).[5]
- On December 3, 2007 Bulgarian dxer "FMDXBG" received Radio Militsaysk, 105.5 MHz via tropo near Gurgulica chalet in eastern Rila, at a distance of 1,312 kilometres (815 mi).[6]
- On December 17, 2007 Polish dxer Maciej Lugowski received 93,7 BBC Radio Scotland from Keelylang Hill transmitter in Gora Kalwaria, Poland. The distance from his site to Orkney Islands is 1,745 km (1,084 mi). BBC Scotland reception lasted for next two days, as extreme tropo ducting was built over Baltic and Northern Sea.[7]
- On November 3, 2008 Swedish Radio Amateur Kjell Jarl SM7GVF contacted Russian Radio Amateur RA6HHT at a distance of 2,315 km (1,438 mi) on 144Mhz.
- On April 23, 2009, a San Antonio-area DXer received WFTS-TV 28's digital signal from Tampa, Florida, at a distance of 995 miles (1,601 km).[8]
- On the late evening of August 24 into the afternoon of August 25, 2009, a DX'er in Burnt River, Ontario, Canada, received several FM radio stations via tropo from Arkansas, Illinois, Iowa, Kansas, Michigan, Missouri, Ohio, Oklahoma, Pennsylvania, and Wisconsin.[9]
- On September 11, 2010, Daniel Albu (Bucharest, Romania) received Radio TRT-FM from Amasya, Turkey at a distance of 922 km.
- On August 9, 2012, Greek dxer Peter "p15able" (Pyrgos, Greece) received Alger Chaîne 2 on 97.5 MHz from Doukhane, Algeria at a distance of 1,228 km.
- On October 07, 2012, Aleksandr (Poltava, Ukraine) received 90.8 MHz - BNR Hristo Botev from Bulgaria (Tsarevo, Burgas Province) at a distance of 980 km during the tropospheric propagation.

References

[1] http://home.twcny.rr.com/nordquistsyr/FMRECDIS.htm
[2] http://home.twcny.rr.com/nordquistsyr/tvrecdis.htm
[3] http://img24.imageshack.us/img24/944/blankrusia1din27august2.png
[4] Jeff Kruszka's Record-Breaking DTV Tropo (http://www.tvdxtips.com/jkdtvtr.html)
[5] Site no longer available (http://web.infoave.net/~fmjnordquist/statistics.html)
[6] FMDXBG Youtube Page (http://www.youtube.com/user/fmdxbg)
[7] http://www.fmdx.pl/thebest.htm
[8] WA5IYX DTV Screen Captures (http://www.qsl.net/wa5iyx/dtv-capt.htm)
[9] Aug 24-25 2009 Es (er, Tropo) (http://www.wtfda.info/showthread.php?p=9817), *WTFDA Forums*, August 28, 2009

- "DXing FAQ" (http://anarc.org/wtfda/dx_faq.htm). *Worldwide TV-FM DX Association*. Retrieved April 25, 2005.
- "William Hepburn's VHF / UHF Tropospheric Ducting Forecast" (http://www.dxinfocentre.com/tropo.html). *William Hepburn's TV & Radio DX Information Centre*. Retrieved June 12, 2006.
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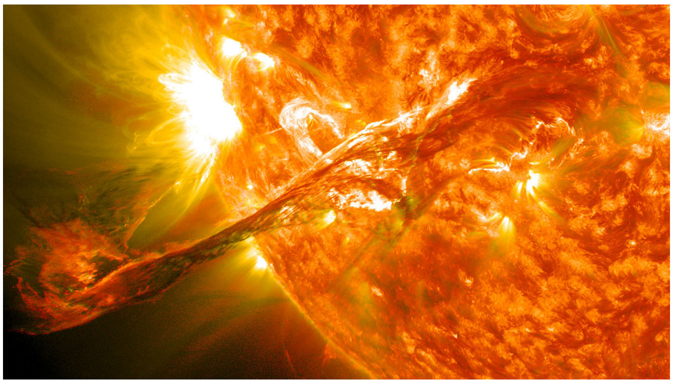
Solar flare

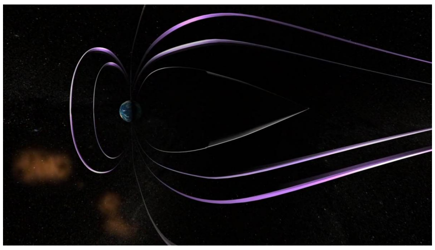
For the class of stars that undergo similar phenomena, see flare star.

"Sun flare" redirects here. For the rose variety, see Rosa 'Sun Flare'.



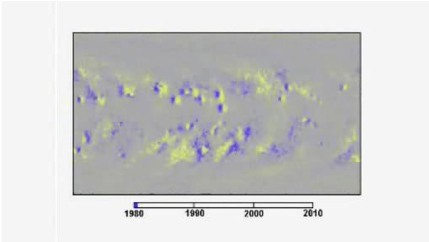
On August 31, 2012 a long prominence/filament of solar material that had been hovering in the Sun's atmosphere, the corona, erupted out into space at 4:36 p.m. EDT

A **solar flare** is a sudden flash of brightness observed over the Sun's surface or the solar limb, which is interpreted as a large energy release of up to 6×10^{25} joules of energy (about a sixth of the total energy output of the Sun each second or 160,000,000,000 megatons of TNT equivalent, over 25,000 times more energy than released from the impact of Comet Shoemaker–Levy 9 with Jupiter). They are often, but not always, followed by a colossal coronal mass ejection also known as a CME. The flare ejects clouds of electrons, ions, and atoms through the corona of the sun into space. These clouds typically reach Earth a day or two after the event.[1] The term is also used to refer to similar phenomena in other stars, where the term **stellar flare** applies.



Heliophysicist Alex Young from NASA Goddard Space Flight Center's predictions for solar activity in 2012.

Solar flares affect all layers of the solar atmosphere (photosphere, chromosphere, and corona), when the plasma medium is heated to tens of millions of kelvins the electrons, protons, and heavier ions are accelerated to near the speed of light. They produce radiation across the electromagnetic spectrum at all wavelengths, from radio waves to gamma rays, although most of the energy is spread over frequencies outside the visual range and for this reason the majority of the flares are not visible to the naked eye and must be observed with special instruments. Flares occur in active regions around sunspots, where intense magnetic fields penetrate the photosphere to link the corona to the solar interior. Flares are powered by the sudden (timescales of minutes to tens of minutes) release of magnetic energy stored in the corona. The same energy releases may produce coronal mass ejections (CME), although the relation between CMEs and flares is still not well established.



Evolution of magnetism on the Sun.

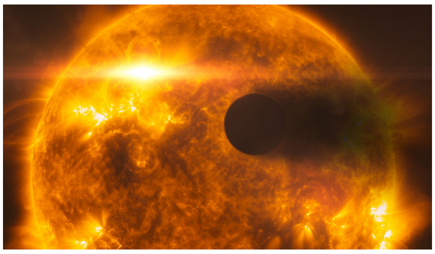
X-rays and UV radiation emitted by solar flares can affect Earth's ionosphere and disrupt long-range radio communications. Direct radio emission at decimetric wavelengths may disturb operation of radars and other devices operating at these frequencies.

Solar flares were first observed on the Sun by Richard Christopher Carrington and independently by Richard Hodgson in 1859[2] as localized visible brightenings of small areas within a sunspot group. Stellar flares have also been observed on a variety of other stars.

The frequency of occurrence of solar flares varies, from several per day when the Sun is particularly "active" to less than one every week when the Sun is "quiet", following the 11-year cycle (the solar cycle). Large flares are less frequent than smaller ones.

Heliophysics
Phenomena
• Solar flare • Geomagnetic storm • Coronal mass ejection • Sunspot • Solar prominence • Solar proton event
This box: • view • talk • edit [3]

Cause

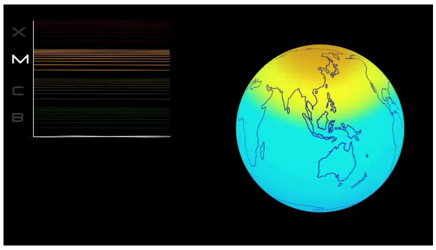

Stellar flare hits HD 189733b (artist's impression).

Flares occur when accelerated charged particles, mainly electrons, interact with the plasma medium. Scientific research has shown that the phenomenon of magnetic reconnection is responsible for the acceleration of the charged particles. On the Sun, magnetic reconnection may happen on solar arcades – a series of closely occurring loops of magnetic lines of force. These lines of force quickly reconnect into a low arcade of loops leaving a helix of magnetic field unconnected to the rest of the arcade. The sudden release of energy in this reconnection is the origin of the particle acceleration. The unconnected magnetic helical field and the material that it contains may violently expand outwards forming a coronal mass ejection.[4] This also explains why solar flares typically erupt from what are known as the active regions on the Sun where magnetic fields are much stronger on average.

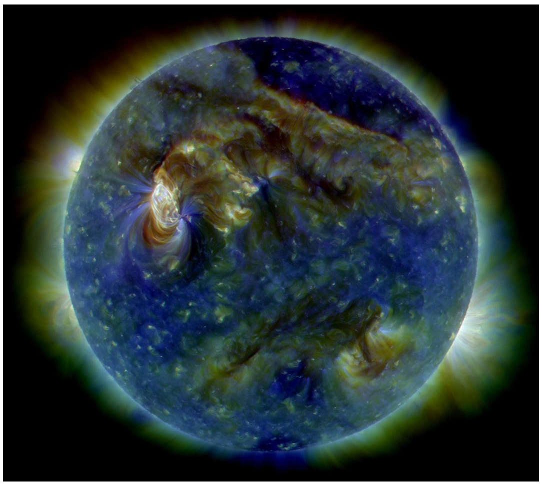
Although there is a general agreement on the flares' causes, the details are still not well known. It is not clear how the magnetic energy is transformed into the particle kinetic energy, nor is it known how the particles are accelerated to energies as high as 10 MeV (mega electron volt) and beyond. There are also some inconsistencies regarding the total number of accelerated particles, which sometimes seems to be greater than the total number in the coronal loop. Scientists are unable to forecast flares, even to this day.Wikipedia:Citation needed

Classification

Solar flares are classified as A, B, C, M or X according to the peak flux (in watts per square metre, W/m^2) of 100 to 800 picometre X-rays near Earth, as measured on the GOES spacecraft.



Powerful X-class flares create radiation storms that produce auroras and can give airline passengers flying over the poles small radiation doses.



On August 1, 2010, the Sun shows a C3-class solar flare (white area on upper left), a solar tsunami (wave-like structure, upper right) and multiple filaments of magnetism lifting off the stellar surface.

Classification	Peak Flux Range at 100-800 picometre
	(Watts/square metre)
A	< 10^{-7}
B	10^{-7} - 10^{-6}
C	10^{-6} - 10^{-5}
M	10^{-5} - 10^{-4}
X	10^{-4} - 10^{-3}
Z Wikipedia:Citation needed	> 10^{-3}

Within a class there is a linear scale from 1 to 9.n (apart from X), so an X2 flare is twice as powerful as an X1 flare, and is four times more powerful than an M5 flare. X class flares up to at least X28 have been recorded.(see below) However, the extreme event in 1859 is theorised to have been well over X40 so a Z class designation is possible.

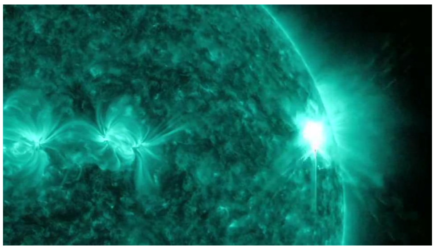
H-alpha classification

An earlier flare classification is based on Hα spectral observations. The scheme uses both the intensity and emitting surface. The classification in intensity is qualitative, referring to the flares as: (**f**)aint, (**n**)ormal or (**b**)rilliant. The emitting surface is measured in terms of *millionths* of the hemisphere and is described below. (The total hemisphere area $A_H = 6.2 \times 10^{12}$ km^2.)

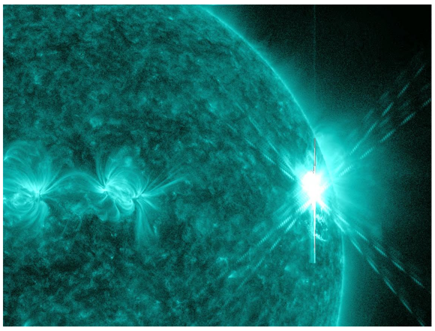
Classification	Corrected Area
	[millionths of hemisphere]
S	< 100
1	100 - 250
2	250 - 600
3	600 - 1200
4	> 1200

A flare then is classified taking **S** or a number that represents its size and a letter that represents its peak intensity, v.g.: **Sn** is a *normal subflare*.

Hazards

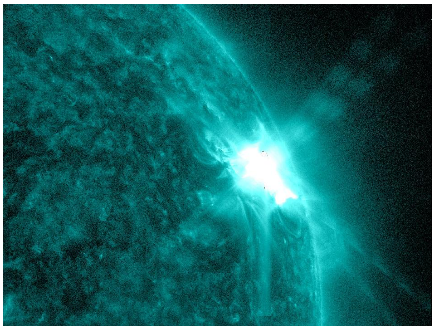

Massive X6.9 class solar flare, August 9, 2011.

Solar flares strongly influence the local space weather in the vicinity of the Earth. They can produce streams of highly energetic particles in the solar wind, known as a solar proton event. These particles can impact the Earth's magnetosphere (see main article at geomagnetic storm), and present radiation hazards to spacecraft and astronauts. Additionally, massive solar flares are sometimes accompanied by coronal mass ejections (CMEs) which can trigger geomagnetic storms that have been known to disable satellites and knock out terrestrial electric power grids for extended periods of time.


While this flare produced a coronal mass ejection (CME), this CME is not traveling towards the Earth, and no local effects are expected.

The soft X-ray flux of X class flares increases the ionization of the upper atmosphere, which can interfere with short-wave radio communication and can heat the outer atmosphere and thus increase the drag on low orbiting satellites, leading to orbital decay. Energetic particles in the magnetosphere contribute to the aurora borealis and aurora australis. Energy in the form of hard x-rays can be damaging to spacecraft electronics and are generally the result of large plasma ejection in the upper chromosphere.

The radiation risks posed by solar flares are a major concern in discussions of a manned mission to Mars, the moon, or other planets. Energetic protons can pass through the human body, causing biochemical damage, presenting a hazard to astronauts during interplanetary travel. Some kind of physical or magnetic shielding would be required to protect the astronauts. Most proton storms take at least two hours from the time of visual detection to reach Earth's orbit. A solar flare on January 20, 2005 released the highest concentration of protons ever directly measured,[5] giving astronauts as little as 15 minutes to reach shelter.


An M7.9 class Solar Flare

Observations

Flares produce radiation across the electromagnetic spectrum, although with different intensity. They are not very intense at *white light*, but they can be very bright at particular atomic lines. They normally produce bremsstrahlung in X-rays and synchrotron radiation in radio.

History

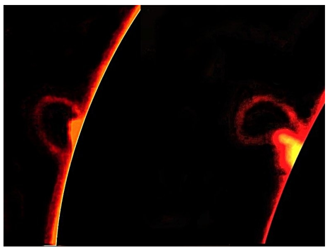
Optical Observations. Richard Carrington observed a flare for the first time on 1 September 1859 projecting the image produced by an optical telescope, without filters. It was an extraordinarily intense *white light flare*. Since flares produce copious amounts of radiation at Hα, adding a narrow (≈1 Å) passband filter centered at this wavelength to the optical telescope, allows the observation of not very bright flares with small telescopes. For years Hα was the main, if not the only, source of information about solar flares. Other passband filters are also used.

Radio Observations. During World War II, on 25 and 26 February 1942, British radar operators observed radiation that Stanley Hey interpreted as solar emission. Their discovery did not go public until the end of the conflict. The same year Southworth also observed the Sun in radio, but as with Hey, his observations were only known after 1945. In 1943 Grote Reber was the first to report radioastronomical observations of the Sun at 160 MHz. The fast development of Radioastronomy revealed new peculiarities of the solar activity like *storms* and *bursts* related to the flares. Today ground-based radiotelescopes observe the Sun from ~100 MHz up to 400 GHz.

Space Telescopes. Since the beginning of Space exploration, telescopes have been sent to space, where they work at wavelengths shorter than UV, which are completely absorbed by the atmosphere, and where flares may be very bright. Since the 1970s, the GOES series of satellites observe the Sun in *soft* X-rays, and their observations became the *standard measure* of flares, diminishing the importance of the Hα classification. *Hard* X-rays were observed by many different instruments, the most important today being the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). Nonetheless, UV observations are today the *stars* of solar imaging with their incredible fine details that reveal the complexity of the solar corona. Spacecraft may also bring radio detectors at very very long wavelengths (as long as a few kilometers) that cannot propagate through the ionosphere.

Optical telescopes

- Big Bear Solar Observatory [6] - Located in Big Bear Lake, California (USA) and operated by the New Jersey Institute of Technology [7] is a solar dedicated observatory with different instruments, and has a huge data bank of full disk Hα images.
- Swedish 1-m Solar Telescope [8] Operated by the Institute for Solar Physics [8] (Sweden), is located in the Observatorio del Roque de los Muchachos [9] on the island of La Palma (Spain).
- McMath-Pierce Solar Telescope located at Kitt Peak National Observatory in Arizona, USA is the world's largest solar telescope.


Two successive photos of a solar flare phenomenon. The solar disc was blocked in these photos for better visualization of the flare's accompanying protruding prominence.

Radio telescopes

- Nançay Radioheliographe (NRH) [10] is an interferometer composed of 48 antennas observing at meter-decimeter wavelengths. The radioheliographe is installed at the Nançay Radio Observatory [11] (France).
- Owens Valley Solar Array (OVSA) [12] is a radio interferometer operated by New Jersey Institute of Technology [7] consisting of 7 antenas observing from 1 to 18 GHz in both left and right circular polarization. OVSA is located in Owens Valley, California, (USA), now is under reform, increasing to 15 the total number of antennas and upgrading its control system.
- Nobeyama Radioheliograph (NoRH) [13] is an interferometer installed at the Nobeyama Radio Observatory [14] (Japan) formed by 84 small (80 cm) antennas, with receivers at 17 GHz (left and right polarization) and 34 GHz operating simultaneously. It observes continuously the Sun, producing daily snapshots. (See link) [15]
- Siberian Solar Radio Telescope (SSRT) [16] is a special-purpose solar radio telescope designed for studying solar activity in the microwave range (5.7 GHz) where the processes occurring in the solar corona are accessible to observation over the entire solar disk. It is a crossed interferometer, consisting of two arrays of 128x128 parabolic antennas 2.5 meters in diameter each, spaced equidistantly at 4.9 meters and oriented in the E-W and N-S directions. It is located [17] in a wooded picturesque valley separating two mountain ridges of the Eastern Sayan Mountains and Khamar-Daban, 220 km from Irkutsk (Russia). Daily solar images are available (See link) [18]
- Nobeyama Radio Polarimeters [19] are a set of radio telescopes installed at the Nobeyama Radio Observatory [14] that observes continuously the full Sun (no images) at the frequencies of 1, 2, 3.75, 9.4, 17, 35, and 80 GHz, at left and right circular polarization.
- Solar Submillimeter Telescope [20] is a single dish telescope, that observes continuously the Sun at 212 and 405 GHz. It is installed at Complejo Astronomico El Leoncito [21] in Argentina. It has a focal array composed by 4 beams at 212 GHz and 2 at 405 GHz, therefore it can locate instantaneously the position of the emitting source [22]. SST is the only solar submillimeter telescope currently in operation.

Space telescopes

The following spacecraft missions have flares as their main observation target.

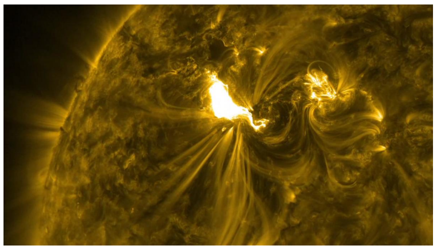
- Yohkoh – The Yohkoh (originally Solar A) spacecraft observed the Sun with a variety of instruments from its launch in 1991 until its failure in 2001. The observations spanned a period from one solar maximum to the next. Two instruments of particular use for flare observations were the Soft X-ray Telescope (SXT), a glancing incidence low energy X-ray telescope for photon energies of order 1 keV, and the Hard X-ray Telescope (HXT), a collimation counting instrument which produced images in higher energy X-rays (15-92 keV) by image synthesis.
- WIND – The Wind spacecraft is devoted to the study of the interplanetary medium. Since the Solar Wind is its main driver, solar flares effects can be traced with the instruments aboard Wind. Some of the WIND experiments are: a very low frequency spectrometer, (WAVES), particles detectors (EPACT, SWE) and a magnetometer (MFI).
- GOES - The GOES spacecraft are satellites in geostationary orbits around the Earth that have measured the soft X-ray flux from the Sun since the mid-1970s, following the use of similar instruments on the Solrad satellites. GOES X-ray observations are commonly used to classify flares, with A, B, C, M, and X representing different powers of ten – an X-class flare has a peak 1-8 Å flux above 0.0001 W/m^2.
- RHESSI – The Reuven Ramaty High Energy Solar Spectral Imager is designed to image solar flares in energetic photons from soft X rays (~3 keV) to gamma rays (up to ~20 MeV) and to provide high resolution spectroscopy up to gamma-ray energies of ~20 MeV. Furthermore, it has the capability to perform spatially resolved spectroscopy with high spectral resolution.
- SOHO – The Solar and Heliospheric Observatory is collaboration between the ESA and NASA which is in operation since December 1995. It carries 12 different instruments, among them the Extreme ultraviolet Imaging Telescope (EIT), the Large Angle and Spectrometric Coronagraph (LASCO) and the Michelson Doppler Imager

(MDI). SOHO is in a halo orbit around the earth-sun L1 point.

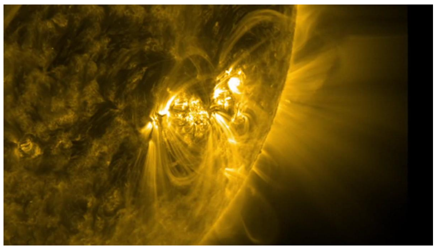
- TRACE – The Transition Region and Coronal Explorer is a NASA Small Explorer program (SMEX) to image the solar corona and transition region at high angular and temporal resolution. It has passband filters at 173 Å, 195 Å, 284 Å, 1600 Å with a spatial resolution of 0.5 arc sec, the best at these wavelengths.
- SDO – The Solar Dynamics Observatory is a NASA project composed of 3 different instruments: the Helioseismic and Magnetic Imager (HMI), the Atmospheric Imaging Assembly (AIA) and the Extreme Ultraviolet Variability Experiment (EVE). It has been operating since February 2010 in a geosynchronous earth orbit.[23]
- Hinode –The Hinode spacecraft, originally called Solar B, was launched by the Japan Aerospace Exploration Agency in September 2006 to observe solar flares in more precise detail. Its instrumentation, supplied by an international collaboration including Norway, the U.K., the U.S., and Africa focuses on the powerful magnetic fields thought to be the source of solar flares. Such studies shed light on the causes of this activity, possibly helping to forecast future flares and thus minimize their dangerous effects on satellites and astronauts.
- ACE – The Advanced Composition Explorer was launched in 1997 into a halo orbit around the earth-sun L1 point. It carries spectrometers, magnetometers and charged particle detectors to analyze the solar wind. The Real Time Solar Wind (RTSW) beacon is continually monitored by a network of NOAA-sponsored ground stations to provide early warning of earth-bound CMEs.

Examples of large solar flares

The most powerful flare ever observed was the first one to be observed, on September 1, 1859, and was reported by British astronomer Richard Carrington and independently by an observer named Richard Hodgson. The event is named the Solar storm of 1859, or the "Carrington event". The flare was visible to a naked-eye (in *white light*), and produced stunning auroras down to tropical latitudes such as Cuba or Hawaii, and set telegraph systems on fire. The flare left a trace in Greenland ice in the form of nitrates and beryllium-10, which allow its strength to be measured today. Cliver and Svalgaard reconstructed the effects of this flare and compared with other events of the last 150 years. In their words: *While the 1859 event has close rivals or superiors in each of the above categories of space weather activity, it is the only documented event of the last ~150 years that appears at or near the top of all of the lists.*



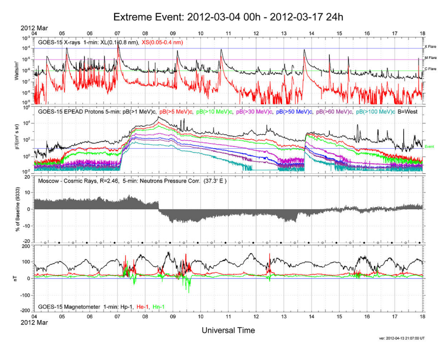
Short narrated video about Fermi's observations of the highest-energy light ever associated with an eruption on the sun as of June 2012



Active Region 1515 released an X1.1 class flare from the lower right of the sun on July 6, 2012, peaking at 7:08 PM EDT. This flare caused a radio blackout, labeled as an R3 on the National Oceanic and Atmospheric Administrations scale that goes from R1 to R5.

In modern times, the largest solar flare measured with instruments occurred on November 4, 2003. This event saturated the GOES detectors, and because of this its classification is only approximate. Initially, extrapolating the GOES curve, it was estimated to be X28. Later analysis of the ionospheric effects suggested increasing this estimate to X45. This event produced the first clear evidence of a new spectral component above 100 GHz.[24]

Other large solar flares also occurred on April 2, 2001 (X20), October 28, 2003 (X17.2 and 10), September 7, 2005 (X17), February 17, 2011 (X2), August 9, 2011 (X6.9), March 7, 2012 (X5.4), July 6, 2012 (X1.1). July 6, 2012- The solar storm hit just after 12 midnight UK time, when an X1.1 solar flare fired out of the AR1515 sunspot. Another X1.4 solar flare from AR 1520 region of the Sun, second in the week, reached the earth on July 15, 2012 with a geomagnetic storm of G1–G2 level. A X1.8-class flare was recorded on October 24, 2012. There has been major solar flare activity in early 2013, notably within a 48 hour period starting on May 12, 2013, a total of four X-class solar flares were emitted ranging from an X1.2 and upwards of an X3.2,[25] the latter of which was one of the largest year 2013 flares.[26][27] Departing sunspot complex AR2035-AR2046 erupted on April 25th 2014 at 0032 UT, producing a strong X1.3-class solar flare and an HF communications blackout on the dayside of Earth. NASA's Solar Dynamics Observatory recorded a flash [28] of extreme ultraviolet radiation from the explosion.



Space Weather—March 2012.

Flare spray

Flare sprays are a type of eruption associated with solar flares. They involve faster ejections of material than eruptive prominences, and reach velocities of 500 to 1200 kilometers per second.

Prediction

Current methods of flare prediction are problematic, and there is no certain indication that an active region on the Sun will produce a flare. However, many properties of sunspots and active regions correlate with flaring. For example, magnetically complex regions (based on line-of-sight magnetic field) called delta spots produce largest flares. A simple scheme of sunspot classification due to McIntosh is commonly used as a starting point for flare prediction. Predictions are usually stated in terms of probabilities for occurrence of flares above M or X GOES class within 24 or 48 hours. The U.S. National Oceanic and Atmospheric Administration (NOAA) issues forecasts of this kind.

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External links

- Real-time space weather (http://spacewx.com/iPhone.html) on the iPhone, iPad, and Android from 150 data streams and 19 institutions.
- Live Solar Images and Data Site (http://sunspotwatch.com/) Includes x-ray flare, geomagnetic, space weather information detailing current solar events.
- Solar Cycle 24 and VHF Aurora Website (www.solarcycle24.com) (http://solarcycle24.com/)
- Solar Weather Site (http://spaceweather.com)
- Current Solar Flare – and geomagnetic activity in dashboard style (www.solar-flares.info) (http://solar-flares.info/)
- STEREO Spacecraft Site (http://stereo.jhuapl.edu)
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- 'The Sun Kings' (http://gresham.ac.uk/event.asp?PageId=45&EventId=695), lecture by Dr Stuart Clark on the discovery of solar flares given at Gresham College, 12 September 2007 (available as a video or audio download as well as a text file).
- An X Class Flare Region on the Sun (http://antwrp.gsfc.nasa.gov/apod/ap071106.html) – NASA Astronomy Picture of the Day
- Sun trek website (http://suntrek.org) An educational resource for teachers and students about the Sun and its effect on the Earth
- NASA – Carrington Super Flare (http://science.nasa.gov/headlines/y2008/06may_carringtonflare.htm?) NASA May 6, 2008
- Archive of the most severe solar storms (http://www.solarstorms.org/SRefStorms.html)
- Animated explanation of Solar Flares from the Photosphere (http://alienworlds.southwales.ac.uk/sunStructure.html#/photosphereflares) (University of South Wales)
- 1 min. 35 sec. Mini documentary: How big are solar flares' prominences? (http://www.youtube.com/watch?v=015cnqMt2i8) A simplified explanation of the size of solar flares' prominences as compared to Earth.

- The Most Powerful Solar Flares Ever Recorded (http://www.spaceweather.com/solarflares/topflares.html) – spaceweather.com (X9+ summary)
- Most Energetic Flares since 1976 (http://users.telenet.be/j.janssens/Flares/Powerflare.html) (X5.7+ details)
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Space weather

Aurora australis observed by *Discovery*, May 1991.

Space weather are the fluid environmental conditions of space, especially near-Earth space[1] or the space from the Sun's atmosphere to the Earth's atmosphere. It is distinct from the concept of weather within the Earth's atmosphere (troposphere and stratosphere). Space weather is the description of changes in the ambient plasma, magnetic fields, radiation, and other influences in space. Much of space weather is driven by energy carried through interplanetary space by the solar wind from regions near the surface of the Sun and the Sun's atmosphere (chromosphere and corona).[2] The term *space weather* is sometimes used to refer to changes in interplanetary (and occasionally interstellar) space.

Space weather has two focal points: scientific research and applications. The term *space weather* was not used until the 1990s. Prior to that time, activities now known as *space weather* were considered to be part of physics or aeronomy or space exploration.

History of the concept

For centuries, people have noticed the aurora, which is caused by space weather, but did not understand it. Navigators in the Middle Ages in Europe using a lodestone as a magnetic compass noted that occasionally the stone's direction was deflected from magnetic north. This was described in 1600 in De Magnete but was not understood to be caused by space weather until the 19th century. Space weather affected the first electrical telegraphs in the 1840 in various areas at various times. The great solar storm of 1859 disrupted telegraph operations around the world, which was covered in many major newspapers at that time. Richard Carrington correctly connected the disruption with a solar flare observed the day before and a great deflection of the Earth's magnetic field (or geomagnetic storm) simultaneous with the telegraph disruption. With this connection, space weather, as we now know it, became a subject of academic research within the study of solar physics. Kristian Birkeland explained the physics of aurora by creating artificial aurora in his laboratory and predicted the solar wind. With the introduction of radio for commercial and military uses, it was noted that periods of extreme static or noise occurred. Severe radar jamming during a large solar event in 1942 led to the discovery of solar radio bursts (radio waves which cover a broad frequency range created by a solar flare), another aspect of space weather.

In the 20th century, the interest in space weather has expanded as military and commercial systems have come to depend on systems affected by space weather. Communications satellites are a vital part of global commerce. Weather satellite systems provide information about terrestrial weather. The signals from satellites of the Global

Positioning System are used in a wide variety of commercial products and processes. Space weather phenomena can interfere with or damage these satellites or interfere with the radio signals to and from these satellites. Space weather phenomena can cause damaging surges in long electrical transmission lines and expose passengers and crew of aircraft travel to radiation,[3][4] especially on polar routes.

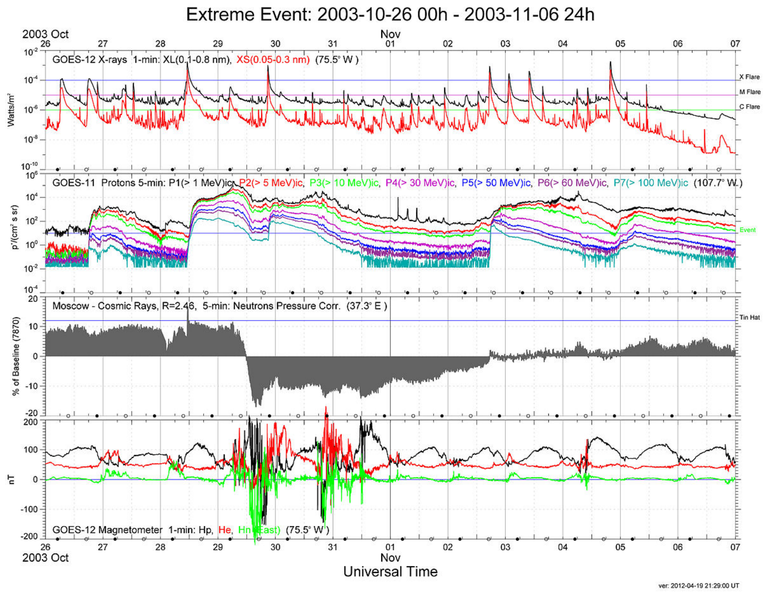
The International Geophysical Year (IGY), created an enormous increase in research into space weather. Ground-based data obtained during IGY demonstrated that the aurora occurred in an *auroral oval*, a permanent region of luminescence 15 to 25 degrees in latitude from the magnetic poles and 5 to 20 degrees wide.[5] In 1958, the Explorer I satellite discovered the Van Allen belts[6] or regions of radiation particles trapped by the Earth's magnetic field. In January 1959, the Soviet satellite Luna 1 first directly observed the solar wind and measured its strength. In 1969, INJUN-5 (a.k.a. Explorer 40[7]) made the first direct observation of the electric field impressed on the Earth's high latitude ionosphere by the solar wind.[8] In the early1970's, Triad data demonstrated that permanent electric currents flowed between the auroral oval and the magnetosphere.[9] From these and other fundamental discoveries, research into space weather has grown exponentially.

Within our own solar system, space weather is greatly influenced by the speed and density of the solar wind and the interplanetary magnetic field (IMF) carried by the solar wind plasma. A variety of physical phenomena are associated with space weather, including geomagnetic storms and substorms, energization of the Van Allen radiation belts, ionospheric disturbances and scintillation of satellite-to-ground radio signals and long-range radar signals, aurora and geomagnetically induced currents at Earth's surface. Coronal mass ejections and their associated shock waves are also important drivers of space weather as they can compress the magnetosphere and trigger geomagnetic storms. Solar energetic particles, accelerated by coronal mass ejections or solar flares, are also an important driver of space weather as they can damage electronics onboard spacecraft (e.g. Galaxy 15 failure), and threaten the life of astronauts.

The term space weather came into usage in the 1990s when it became apparent that the impact of the space environment on human systems demanded a more coordinated research and application framework. The purpose of the National Space Weather Program in the USA is to focus research on the needs of the commercial and military communities which are affected by space weather, to connect the research community to the user community, to create coordination between operational data centers and to create better definitions of what the user community needs are. The concept was turned into an action plan in 2000,[10] an implementation plan in 2002, an assessment in 2006[11] and a revised strategic plan in 2010.[12] A revised action plan will be released in 2011 and a revised implementation plan will be release in 2012. One part of the National Space Weather Program is to make users aware that space weather affects their business.[13] Private companies now acknowledge space weather "is a real risk for today's businesses".

Effect of space weather on space systems

Spacecraft anomalies



GOES-11 and GOES-12 monitored space weather conditions during the October 2003 solar activity.

Spacecraft malfunction for a variety of reasons. Some malfunctions are reported [14] but many are not reported. A few failures can be directly attributed to space weather; many more failures are suspected to have a space weather component; and many failures are unrelated to space weather. One indicator that space weather is a significant driver of spacecraft failure is that 46 of the 70 failures reported in 2003 occurred during the October 2003 geomagnetic storm. The two most common adverse space weather effects on spacecraft are radiation damage and spacecraft charging. Radiation (high energy particles) passes through the skin of the spacecraft and into the electronic components. In most cases the radiation causes an erroneous signal or changes one bit in memory of a spacecraft's electronics (single event upsets). In a few cases, the radiation destroys a section of the electronics (single-event latchup). Spacecraft charging is the accumulation of an electrostatic charge on a non-conducting material on the spacecraft's surface by low energy particles. If enough charge is built-up, a discharge (spark) occurs. Damage to the spacecraft is done by causing an erroneous signal to be detected and acted on by the spacecraft computer as if the signal came from the ground controller or the electronics are damaged by a surge of electrical current. A recent study indicates that spacecraft charging is the predominant space weather effect on spacecraft in geosynchronous orbit.

Spacecraft orbit changes

The orbits of spacecraft in low Earth orbit (LEO) decay to lower and lower altitudes due to the resistance from the friction between the spacecraft's surface (*i.e.* , drag) and the outer layer of the Earth's atmosphere (a.k.a. the thermosphere and exosphere). Eventually, a spacecraft's orbit will decay so much that it will fall out of orbit and crash to the Earth's surface. Many spacecraft launched in the past couple of decades have the ability to fire a small rocket (1) to increase the altitude to compensate for the decay and extend the lifetime in space, (2) to re-enter the atmosphere and crash into the ocean, or (3) change the orbit to avoid collision with other spacecraft. In order to accomplish the goal of firing a small rocket, very precise information about the orbit is needed. A geomagnetic storm can cause an orbit change over a couple of days that otherwise would occur over a year or more. The geomagnetic storm adds heat to the thermosphere, causing the thermosphere to expand and rise, which increases the drag on spacecraft in low Earth orbits. The 2009 satellite collision between the Iridium 33 and Cosmos 2251 demonstrated the importance of having precise knowledge of all objects in orbit. Iridium 33 had the capability to maneuver out of the path of Cosmos 2251 and could have evaded the crash, if a credible collision prediction had been available,

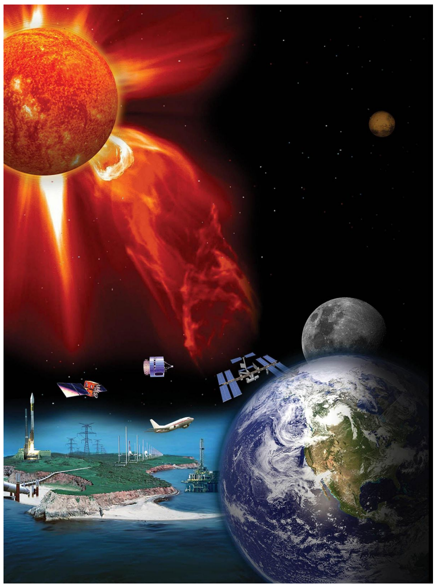
Effect of radiation on humans in space

Main article: Effect of spaceflight on the human body

The exposure of a human body to ionizing radiation has the same harmful effects whether the source of the radiation is a medical X-ray machine, a nuclear power plant or radiation in space. The degree of the harmful effect depends on the length of exposure and the energy density of the radiation. The ever-present radiation belts extend down to the altitude of manned spacecraft such as the International Space Station (ISS) and the Space Shuttle but the amount of exposure is within the acceptable lifetime exposure limit under normal conditions. During a major space weather event which includes a burst of solar energetic particles, the flux can increase by one to several orders of magnitude. There are areas within ISS where the thickness of the spacecraft surface and equipment can provide extra shielding and may keep the total dose absorbed within lifetime safe limits.[15] For the Shuttle, such an event would have required an immediate termination of the mission.

Effects of space weather on ground systems

Disruption of GPS and other spacecraft signals



Art inspired from the concept of space weather

The ionosphere bends radio waves in the same manner that water in a swimming pool bends visible light. When the medium through which the light or radio waves travel is disturbed, the light image or radio information is distorted and can become unrecognizable. The degree of distortion (scintillation) of a radio wave by the ionosphere depends on the frequency of the radio signal. Radio signals in the VHF band (30 to 300 MHz) can be distorted beyond recognition by a disturbed ionosphere. Radio signals in the UHF band (300 MHz to 3 GHz) will propagate through a disturbed ionosphere but a receiver may not be able to keep locked to the carrier frequency. The Global Positioning System uses signals at 1575.42 MHz (L1) and 1227.6 MHz (L2) which can be distorted by a disturbed ionosphere and a receiver computes an erroneous position or fails to compute any position. Because the GPS signals are used by wide range of applications, any space weather event which makes GPS signal unreliable, the impact on society can be significant. For example the Wide Area Augmentation System (WAAS) operated by the Federal Aviation Administration is used as a precision navigation tool for commercial aviation in North America. It is disabled by every major space weather event. In some cases WAAS is disabled for minutes and in a few cases it has been disabled for a few days. Major space weather events can push the disturbed polar ionosphere 10° to 30° of latitude toward the equator and can cause large ionospheric gradients (changes in density over distance of 100's of km) at mid and low latitude. Both of these factors can distort GPS signals.

Disruption of long-distance radio signals

Radio wave in the HF band (3 to 30 MHz) (also known as the shortwave band) are bent so much by the ionosphere that they are reflected back in the same manner as a mirror reflects light. Since the ground also reflects HF wave, a signal can be transmitted around the curvature of the Earth to a distant station. During the 20th century, HF communications was the only method for a ship or aircraft far from land or a base station to communicate. With the advent of systems such as Iridium, there are now other methods of communications but HF is still considered to be critical because not all vessels carry the newer equipment and even if the newer equipment is on board, HF is considered a critical backup system. Space weather events can create irregularities in the ionosphere that scatter HF signals instead of reflecting them and make HF communications over long distance poor or impossible. At auroral and polar latitudes, small space weather events which occur frequently disrupt HF communications. At mid-latitudes, HF communications are disrupted by solar radio bursts, by X-rays from solar flares (which enhance and disturb the ionospheric D-layer) and by TEC enhancements and irregularities during major geomagnetic storms which are infrequent.

Transpolar routes flown by airplanes are particularly sensitive to space weather, in part because of Federal Aviation Regulations requiring reliable communication over the entire flight.[16] It is estimated to cost about $100,000 each time such a flight is diverted from a polar route.

Effect of radiation on humans at and near ground level

The Earth's magnetic field guides cosmic ray and solar energetic particles to polar latitudes and radiation particles enter the mesosphere and stratosphere. Cosmic rays at the top of the atmosphere shatter atmospheric atoms and create lower energy, but still harmful, radiation particles which penetrate deep into the atmosphere. All aircraft flying above 10 km (33,000 feet) altitude are exposed to a noticeable amount of radiation. The exposure is greater in polar regions than at mid-latitude and equatorial regions. Many commercial aircraft from Europe and North America to East Asia fly over the polar region. When a space weather event causes radiation exposure to exceed the safe level set by aviation authorities,[17] the aircraft's flight path is deviated to avoid the polar region.

Ground Induced Current: electrical transmission, pipelines, etc

A well-known ground-level consequence of space weather is geomagnetically induced current, or ground induced current or GIC. GIC flows through the ground to depths of 20 km or more during geomagnetic storms. A well-known example of the adverse effect of a GIC event is the collapse of the Hydro-Québec power network on March 13, 1989. This was started by a failure of an overloaded transformer, which led to a general blackout, which lasted more than 9 hours and affected 6 million people. The geomagnetic storm causing this event was itself the result of a Coronal Mass Ejection, ejected from the Sun on March 9, 1989.[18] A large geomagnetic storm can affect electric power grids at all latitudes,[19] A storm as large as the 1859 event could disable the entire electric power grid in Eastern Canada and Eastern United States. GICs enter power grids, pipelines[20][21] and other conducting networks through grounding wires. Pipelines and other activities at high latitudes are affected by GIC driven by modest levels of auroral activity which occur almost daily. GICs associated with space weather can affect other systems such as geophysical mapping and hydrocarbon production.

Geophysical exploration

Air and ship borne magnetic surveys can be affected by rapid magnetic field variations during geomagnetic storms. Geomagnetic storms cause data interpretation problems because the space-weather-related magnetic field changes are similar in magnitude to those of the sub-surface crustal magnetic field in the survey area. Accurate geomagnetic storm warnings, including an assessment of the magnitude and duration of the storm, allows for an economic use of survey equipment.

Geophysics and hydrocarbon production

For economic and other reasons, oil and gas production often involves the directional drilling of well paths many kilometers from a single wellhead in both the horizontal and vertical directions. Accuracy requirements are strict, due to target size – reservoirs may only be a few tens to hundreds of meters across – and for safety reasons, because of the proximity of other boreholes. Surveying by the most accurate gyroscopic method is expensive, since it can involve the cessation of drilling for a number of hours. An alternative is to use a magnetic survey, which enables measurement while drilling (MWD). Near real time magnetic data can be used to correct the drilling direction and nearby magnetic observatories prove vital.[22][23] Magnetic data and space weather forecasts can also be helpful in clarifying unknown sources of drilling error on an on-going basis.

Effect of space weather on terrestrial weather

The amount of energy entering the troposphere and stratosphere from all space weather phenomena is trivial compared to the solar insolation in the visible and infra-red portions of the solar electromagnetic spectrum. However there does seem to be some linkage between the 11-year sunspot cycle and the Earth's climate.[24] For example, the Maunder minimum, a 70-year period almost devoid of sunspots, correlates to a cooling of the Earth's climate. One suggestion for the linkage between space and terrestrial weather is that changes in cosmic ray flux cause changes in the amount of cloud formation.[25] Another suggestion is that variations in the EUV flux subtly influence existing drivers of the climate and tips the balance between states such as the El Niño/La Niña states.[26] However, a linkage between space weather and the climate has not been demonstrated conclusively.

Observations of space weather

The observation of space weather is done both for scientific research and for applications. The type of observation done for science has varied over the years as the frontiers of our understanding has increased and due to competition for resources from other types of space-related research. The observations related to applications have been more systematic and has expanded over the years as awareness and applications have increased.

Observing space weather from the ground

Presently, space weather is monitored at ground level by observing changes in the Earth's magnetic field over periods of seconds to days, by observing the surface of the Sun and by observing radio noise created in the Sun's atmosphere.

The Sunspot Number (SSN) is the number of sunspots on the Sun's photosphere in visible light on the side of the Sun visible to an Earth observer. The number and total area of sunspots are related to the brightness of the Sun in the extreme ultraviolet (EUV) and X-ray portions of the solar spectrum and to solar activity such as solar flares and coronal mass ejections (CMEs).

10.7 cm radio flux (F10.7) is a measurement of RF emissions from the Sun and is approximately correlated with the solar EUV flux. Since this RF emission is easily obtained from the ground and EUV flux is not, this value has been measured and disseminated continuously since 1947. The world standard measurements are made by the Dominion Radio Astrophysical Observatory at Penticton, B.C., Canada and reported once a day at local noon[27] in solar flux units (10^{-22}W·m^{-2}·Hz^{-1}). F10.7 is archived by the National Geophysical Data Center.[28]

Fundamental space weather monitoring data are provided by ground-based magnetometers and magnetic observatories. Indeed, magnetic storms were first discovered by ground-based measurement of occasional magnetic disturbance. Ground magnetometer data are used for informing real-time situational awareness, for post-event analysis of effects, and because many magnetic observatories have been in continuous operations for decades to centuries, their data also inform studies of long-term changes in space climatology.

Dst index is an estimate of the magnetic field change at the Earth's magnetic equator due to a ring of electrical current at and just earthward of GEO.[29] The index is based on data from four ground-based magnetic observatories between 21° and 33° magnetic latitude during a one-hour period. Stations closer to the magnetic equator are not used due to ionospheric effects. The Dst index is compiled and archived by the World Data Center for Geomagnetism, Kyoto[30]

Kp/ap Index: 'a' is an index created from the geomagnetic disturbance at one mid-latitude (40° to 50° latitude) geomagnetic observatory during a 3-hour period. 'K' is the quasi-logarithmic counterpart of the 'a' index. Kp and ap are the average of K and an over 13 geomagnetic observatories to represent planetary-wide geomagnetic disturbances. The Kp/ap index[31] indicates both geomagnetic storms and substorms (auroral disturbance). Kp/ap is available from 1932 onward.

AE index is compiled from geomagnetic disturbances at 12 geomagnetic observatories in and near the auroral zones and is recorded at 1-minute intervals. The AE index is made public with a delay of two to three days, which severely limits its utility for space weather applications. The AE index indicates the intensity of geomagnetic substorms except during a major geomagnetic storm when the auroral zones expand equatorward from the observatories.

Radio noise burst are observed and reported by the Radio Solar Telescope Network to the U.S. Air Force and to NOAA. The radio bursts are associated with plasma from a solar flare interacting with the ambient solar atmosphere.

The Sun's photosphere is observed continuously by a series of observatories[32] for activity which can be the precursors to solar flares and CMEs. The Global Oscillation Network Group (GONG)[33] project monitors both the surface and the interior of the Sun by using helioseismology, the study of sound waves propagating through the Sun and observed as ripples on the solar surface. GONG can detect sunspot groups on the far side of the Sun. This ability has recently been verified by visual observations from the NASA STEREO spacecraft.

Neutron monitors on the ground indirectly monitor cosmic rays from the Sun and galactic sources. Cosmic rays do not reach the Earth's surface due to the shielding of the Earth's magnetic field and atmosphere. When cosmic rays interact with the atmosphere, atomic interactions occur which cause a shower of lower energy particles to descend deeper into the atmosphere and to ground level. The presence of cosmic rays in the near-Earth space environment can be detected by monitoring high energy neutrons at ground level. Small fluxes of cosmic rays are present continuously. Large fluxes are produced by the Sun during events related to energetic solar flares.

Total Electron Content (TEC) is a measure of the ionosphere over a given location. TEC is the number of electrons in a column one meter square from the base of the ionosphere (approximately 90 km altitude) to the top of the ionosphere (approximately 1000 km altitude). Many of the measurements of TEC are made by monitoring the two frequencies transmitted by GPS spacecraft. Presently GPS TEC is monitored and distributed in real time from more than 360 stations maintained by numerous agencies in many countries.

Geoeffectiveness is a measure of how strongly the magnetic fields of space weather events, such as coronal mass ejections, will couple with the Earth's magnetic field. This is determined by the direction the magnetic field held within the plasma that originates from the sun. New techniques measuring Faraday Rotation in radio waves are being developed to measure the direction of the magnetic field.

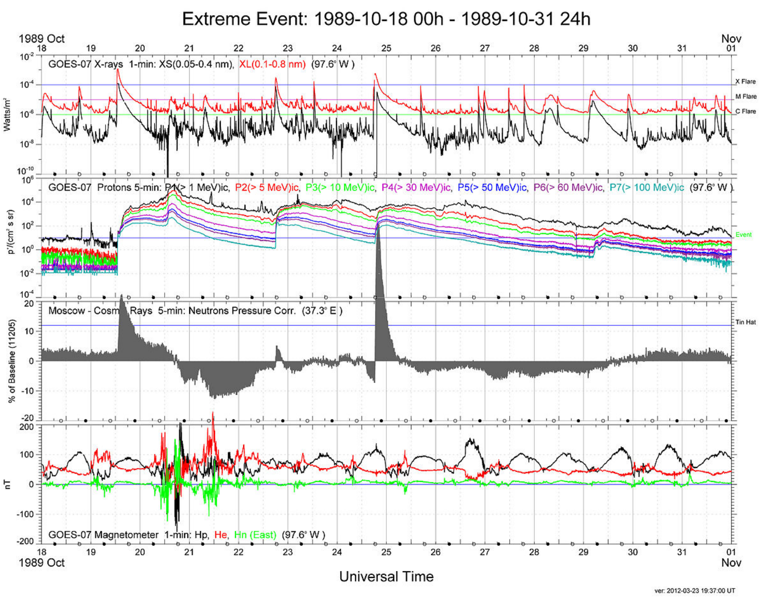
Observing space weather with satellites

After Explorer I discovered that space was not a void, many research spacecraft have been launched to discover and characterize the space environment. There have been too many spacecraft since then to list them all here and they have carried a wide variety of instruments.[34][35][36][37][38] The spacecraft of the Orbiting Geophysical Observatory series were among the first spacecraft with the mission of discovering the space environment. Significant recent spacecraft are the NASA-ESA Solar-Terrestrial Relations Observatory (STEREO) pair of spacecraft launched in 2006 into solar orbit and the Van Allen Probes, launched in 2012 into a highly elliptical Earth-orbit. The two STEREO spacecraft drift away from the earth by about 22° per year, one leading and the other trailing the earth in its orbit. Together they compile information about the Sun's surface and atmosphere in three dimensions. The Van Allen probes are obtaining detailed information about the radiation belts, geomagnetic storms and the relationship between the two.

The mission of most spacecraft is unrelated to gathering information about the space environment for research or applications, but some of these other spacecraft have carried auxiliary instrument or had some part of their primary payload used for space weather. Some of the earliest such spacecraft were part of the Applications Technology Satellite[39] (ATS) series at GEO which were precursors to the modern Geostationary Operational Environmental Satellite (GOES) weather satellite and many communication satellites. The ATS spacecraft carried environmental particle sensors as auxiliary payloads and had their navigational magnetic field sensor used for sensing the environment.

Many of the earliest instruments used for monitoring the space environment were and are research spacecraft which were re-purposed or jointly purposed for space weather applications and forecasting. One of the first of these is the IMP-8 (Interplanetary Monitoring Platform)[40] The IMP-8 orbited the Earth at 35 Earth Radii and observed the solar wind for two-thirds of its 12-day orbit from 1973 to 2006. Since the solar wind carries disturbances which affect the magnetosphere and ionosphere, IMP-8 demonstrated the utility of continuously monitoring the solar wind. IMP-8 was followed by ISEE-3 which was placed near the L_1 Sun-Earth Lagrangian point, 235 Earth radii above the surface (about 1.5 million km, or 924,000 miles) and continuously monitored the solar wind from 1978 to 1982. The next spacecraft to monitor the solar wind at the L_1 point was WIND from 1994 to 1998. After April 1998, the WIND spacecraft orbit was change to circle the Earth and pass by the L_1 point occasionally. The NASA Advanced Composition Explorer (ACE) has monitored the solar wind at the L_1 point from 1997 to present. It is estimated to cease operating about 2024. Funding for a replacement for ACE is in the 2012 budget request for NOAA with a planned launch in 2015. The replacement's primary mission will be space weather forecasting and applications.

In addition to monitoring the solar wind, monitoring the Sun is important to space weather. Because the solar EUV cannot be monitored from the ground, the joint NASA-ESA Solar and Heliospheric Observatory (SOHO) spacecraft was launched and has provide EUV images of the Sun from 1995 to the present. SOHO is a main source of near-real time solar data for both research and space weather prediction and inspired the STEREO mission. The Yohkoh spacecraft at LEO observed the Sun from 1991 to 2001 in the X-ray portion of the solar spectrum and was useful for both research and space weather prediction. Data from Yohkoh inspired the Solar X-ray Imager on GOES.



GOES-7 monitors space weather conditions during the October 1989 solar activity resulted in a Forbush Decrease, Ground Level Enhancements, and many satellite anomalies.

Spacecraft with instruments whose primary purpose is to provide data for space weather predictions and applications include the Geostationary Operational Environmental Satellite (GOES) series of spacecraft, the POES series, the DMSP series, and the Meteosat series. The GOES spacecraft have carried an X-ray sensor (XRS) which measures the flux from the whole solar disk in two bands – 0.05 to 0.4 nm and 0.1 to 0.8 nm – since 1974, an X-ray imager (SXI) since 2004, a magnetometer which measures the distortions of the Earth's magnetic field due to space weather, a whole disk EUV sensor since 2004, and particle sensors (EPS/HEPAD) which measure ions and electrons in the energy range of 50 keV to 500 MeV. Starting sometime after 2015, the GOES-R generation of GOES spacecraft will replace the SXI with a solar EUV image (SUVI) similar to the one on SOHO and STEREO and the particle sensor will be augmented with a component to extend the energy range down to 30 eV.

Space weather modeling

Space weather models are computer simulations of the space weather environment. Like computer models for meteorology, space weather models take a limited set of data values and extrapolate to values which describe the entire space weather environment or a segment of the space weather environment in the model. Each model makes a prediction or a set of predictions about how the environment evolves with time. Computer models use the sets of mathematical equations to describe the physical processes involved. The early space weather models were heuristic; *i.e.,* they relate one phenomenon with another without including any physics in the relationship. Some of these simple models are still used because they take minimal resources and yield results which are good enough for some purposes. Present research and development efforts concentrate on complex sets of equations which account for as many elements of physics as possible. Space weather models differ from meteorological model in that amount of input is vastly smaller and no single space weather model yet can reliably predict the environment from the surface of the Sun to the bottom of the Earth's ionosphere.

A significant portion of space weather model research and development in the past two decades has been done as part of the Geospace Environmental Model (GEM) program of the National Science Foundation.Two major centers for modeling are the Center for Space Environment Modeling (CSEM)[41] and the Center for Integrated Space weather Modeling (CISM).[42] The Community Coordinated Modeling Center[43] (CCMC) at the NASA Goddard Space Flight Center is a facility for coordinating the development and testing of research models, for the improvement of models and for preparing models for transition to space weather prediction and application.[44]

Modeling efforts to simulate the environment from the Sun to the Earth use several method including (a) magnetohydrodynamics in which the environment is treated as a fluid, (b) *particle in cell* in which non-fluid interactions are handled within a cell and then a series of cells are connected together to describe the environment, (c) *first principles* in which physical processes are in balance (or equilibrium) with one another, (d) *semi-static* modeling in which a statistical or empirical relationship is described, or a combination of several of these methods.

Commercial space weather activities

After the start of the space weather discipline in the 1990s, and particularly after 2000, there has been a growing community of commercial space weather providers. These are mostly small companies, that provide a variety of space weather data, models, derivative products, and service distribution for government, commercial, and consumer customers. On April 29, 2010, the commercial space weather community evolved from the Commercial Space Weather Interest Group (CSWIG) that had met for a decade at Space Weather Workshop in Boulder, Colorado every spring, into the American Commercial Space Weather Association (ACSWA [45]). It is a formal industry association representing private-sector commercial interests related to space weather.

ACSWA [45] promotes space weather risk mitigation for critical national infrastructure related to national daily life, economic strength, and national security. ACSWA, as an association and in conjunction with its member companies, is playing a vital role by identifying important data and technology gaps that can be filled by private or government actions and by developing value-added products and services for the benefit of human and property safety as well as for vibrant commerce.

The goals of ACSWA are to:

1. provide quality space weather data and services to help mitigate risks to technology that is vital to the country and government;
2. provide advisory services regarding space weather to government agencies;
3. provide guidance to government agencies on what tasks can be better provided by commercial space weather providers versus government agencies;
4. represent the interests of commercial space weather providers;
5. represent commercial space weather capabilities in the national and international arena;
6. and develop operational space weather best-practices.

A summary of the broad technical capabilities in space weather that are available from the association can be found on their web site [46].

Notable space weather events

- On the night of December 21, 1806, Alexander von Humboldt observed that his compass had become erratic during a bright auroral event.
- The Solar storm of 1859 causes widespread disruption of telegraph service.
- The Aurora of November 17, 1882 disrupts telegraph service.
- The May 1921 geomagnetic storm,[47] one of the largest geomagnetic storms causes worldwide disruption of telegraph service and damage to electrical equipment.
- August 7, 1972, a large Solar Energetic Particles event occurred. If astronauts had been in space at the time, the dose would have been deadly or at least life-threatening.[48] Fortunately, this large event happened between the Apollo 16 and Apollo 17 lunar missions.
- The March 1989 geomagnetic storm included the full array of space weather effects: Solar Energetic Particles, Coronal Mass Ejection, Forbush decrease, ground level enhancement, geomagnetic storm, etc..
- The 2000 Bastille Day event produces exceptionally bright aurora.
- April 21, 2002, the Nozomi Mars Probe was hit by a large Solar Energetic Particles event which caused large-scale failure. The mission, which was already about 3 years behind schedule, was eventually abandoned in December 2003.[49]

Notes

[1] **Near-earth space** is defined as the region from the interface between the solar wind and the Earth into the magnetosphere and down to the ionosphere and thermosphere.

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[15] (http://www.newscientist.com/article/dn2956-space-station-radiation-shields-disappointing.html) Space station radiation shields disappointing, New Scientist, 23 October 2002

[16] FAA Advisory Circular 120-42B, June 6, 2008, Extended Operations (ETOPS and Polar Operations)

[17] FAA Advisory Circular 120-52, March 5, 1990, Radiation exposure of air carrier crew members

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[30] (http://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html) World Data Center for Geomagnetism, Kyoto

[31] (http://www-app3.gfz-potsdam.de/kp_index/) Helmholtz Centre PotsdamGFZ German Research Centre for Geosciences

[32] (http://www.swpc.noaa.gov/solar_sites.html) List of solar observatories

[33] (http://gong.nso.org) Global Oscillation Network Group home page

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[41] (http://csem.engin.umich.edu) Univ. of Michigan Center for Space Environment Modeling

[42] (http://www.bu.edu/cism/) Boston Univ. Center for Integrated Space Weather Modeling

[43] (http://ccmc.gsfc.nasa.gov/) NASA Community Coordinated Modeling Center

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External links

Real-time space weather forecast

- (http://www.swpc.noaa.gov/SWN/) NOAA-SWPC Space Weather Now - (U.S. National Oceanic and Atmospheric Administration [NOAA])
- (http://www.spaceweather.gc.ca/index-eng.php) Space Weather Canada site
- (http://www.spacewx.com/Space_Weather_Now.html) Space Environment Technologies' real-time space weather
- (http://sw22.spaceweather.usu.edu/index.html) Utah State Univ SWC Real-time GAIM Ionosphere - (real-time model of ionosphere)
- (http://prop.hfradio.org/) Space Weather and Radio Propagation. Live and historical data and images with a perspective on how it affects radio propagation
- (http://www.lmsal.com/solarsoft/last_events/) Latest Data from STEREO, HINODE and SDO (Large bandwidth)
- (http://www.spaceweather.com/) Spaceweather.com - Space Weather news, forecasts and pictures
- (http://www.geomag.bgs.ac.uk/research/space_weather/spweather.html) British Geological Survey's Space Weather site

Other links

- Space Weather FX (http://www.haystack.mit.edu/edu/poa/swfx/index.html) - Video podcast series on Space Weather from MIT Haystack Observatory
- ESA's Space Weather Site (http://esa-spaceweather.net/)
- Space Weather European Network (http://www.esa-spaceweather.net/swenet/) - (ESA)
- SpaceWeather.com (http://www.spaceweather.com/) - News and information about meteor showers, solar flares, auroras, and near-Earth asteroids
- (http://www.acswa.us) - American Commercial Space Weather Association (ACSWA)
- (http://www.aer.com) - Atmospheric and Environmental Research (AER)
- (http://astraspace.net) - Atmospheric and Space Technology Research Associates (ASTRA)
- (http://www.carmelresearchcenter.com) - Carmel Research Center (CRC)
- (http://www.cpi.com) - Computational Physics, Incorporated (CPI)
- (http://www.expi.com) - Exploration Physics International (EXPI)
- (http://www.flareforecast.com) - Flare Forecast LLC (FF)
- (http://geooptics.com) - GeoOptics (GeoOptics)
- (http://www.planetiq.com) - PlanetIQ, LLC (PlanetIQ)
- (http://www.predsci.com) - Predictive Sciences, Inc. (PSI)
- (http://q-upnow.com) - Q-Up Now (Q-up)
- (http://www.sci-sol.com) - Scientific Solutions, Inc. (SSI)
- (http://spacenv.com) - Space Environment Corporation (SEC)
- (http://spacewx.com) - Space Environment Technologies (SET)
- (http://spaceservicesinc.com) - Space Services Holdings, Inc. (SSH)
- (http://www.swftt.net) - Space Weather For Today and Tomorrow (SWFTT)
- (http://solarstormconsultant.com) - Storm Analysis Consultants (SAC)
- (http://spaceweather.usu.edu) - Utah State University Space Weather Center (SWC)

Amateur radio frequency allocations

Amateur radio

- Amateur radio direction finding
- Amateur radio emergency communications
- Amateur radio high bands
- Amateur radio homebrew
- Amateur radio operating award
- Amateur radio station
- Amateur television
- Antenna theory
- Automatic Link Establishment
- Automatic Packet Reporting System
- Contesting
- DX communication
- DX-pedition
- Hamfest
- High speed multimedia
- High Speed Telegraphy
- Internet Radio Linking Project
- OSCAR
- Packet radio
- Portable operation (amateur radio)
- QRP operation
- QSL card
- Special event station
- Skywarn
- Vintage amateur radio

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Amateur radio frequency allocation is done by national telecommunications authorities. Globally, the International Telecommunication Union (ITU) oversees how much radio spectrum is set aside for amateur radio transmissions. Individual amateur stations are free to use any frequency within authorized frequency ranges; authorized bands may vary by the class of the station license.

Radio amateurs use a variety of transmission modes, including Morse code, radioteletype, data, and voice. Specific frequency allocations vary from country to country and between ITU regions as specified in the current ITU HF frequency allocations [2] for amateur radio. The modes and types of allocations within each range of frequencies is called a bandplan, and may be set by international agreements, national regulations, or agreements between amateur radio operators.

National authorities regulate amateur usage of radio bands. Some bands may not be available or may have restrictions on usage in certain countries or regions. International agreements assign amateur radio bands which differ by region.[3]

Band characteristics

Medium frequency

See also: Medium frequency

- **160 meters** – 1.8-2 MHz (1800–2000 kHz) – Often taken up as a technical challenge; as long distance (DX) propagation tends to be more difficult due to higher D-layer ionospheric absorption. Long distance propagation tends to occur only at night, and the band can be notoriously noisy particularly in the summer months. 160 meters is also known as the "top band". Allocations in this band vary widely from country to country. This band lies just above the commercial AM broadcast band.

High frequency

See also: High frequency

- **80 meters** – 3.5-4 MHz (3500–4000 kHz) – Best at night, with significant daytime signal absorption. Works best in winter due to atmospheric noise in summer. Only countries in the Americas and few others have access to all of this band, in other parts of the world amateurs are limited to the bottom 300 kHz or less. In the US and Canada the upper end of the sub-band from 3600–4000 kHz, permits use of single-sideband voice as well as amplitude modulation, voice ; often referred to as 75 meters.
- **60 meters** – 5 MHz region – A relatively new allocation and originally only available in a small number of countries such as the United States, United Kingdom, Ireland, Norway, Denmark, and Iceland, but now continuing to expand. In most (but not all) countries, the allocation is channelized and may require special application. Voice operation is generally in upper sideband mode and in the USA it is mandatory.
- **40 meters** – 7.0–7.3 MHz – Considered the most reliable all-season DX band. Popular for DX at night, 40 meters is also reliable for medium distance (1500KM) contacts during the day. Much of this band was shared with broadcasters, and in most countries the bottom 100 kHz or 200 kHz are available to amateurs. However, due to the high cost of running high power commercial broadcasting facilities; decreased listener-ship and increasing competition from net based international broadcast services, many 'short wave' services are being shut down leaving the 40 meter band free of other users for amateur radio use.
- **30 meters** – 10.1–10.15 MHz – a very narrow band, which is shared with non-amateur services. It is recommended that only Morse Code and data transmissions be used here, and in some countries amateur voice transmission is actually prohibited. In the US, data, RTTY and CW are the only modes allowed AND at a maximum 200w PEP power output. Not released for amateur use in a small number of countries. Due to its location in the centre of the shortwave spectrum, this band provides significant opportunities for long-distance communication at all points of the solar cycle. 30 meters is a WARC band. "WARC" bands are so called due to the special World Administrative Radio Conference allocation of these newer bands to amateur radio use. Amateur radio contests are not run on the WARC bands.
- **20 meters** – 14.0–14.35 MHz – Considered the most popular DX band; usually most popular during daytime. QRP operators recognize 14.060 MHz as their primary calling frequency in that band. Users of the PSK31 data mode tend to congregate around 14.071 MHz. Analog SSTV activity is centered around 14.230 MHz.
- **17 meters** – 18.068–18.168 MHz – Similar to 20m, but more sensitive to solar propagation minima and maxima. 17 meters is a WARC band.

- **15 meters** – 21–21.45 MHz – Most useful during solar maximum, and generally a daytime band. Daytime sporadic-E propagation (1500 km) occasionally occurs on this band.
- **12 meters** – 24.89–24.99 MHz – Mostly useful during daytime, but opens up for DX activity at night during solar maximum. 12 meters is one of the new WARC bands.
- **10 meters** – 28–29.7 MHz – Best long distance (e.g., across oceans) activity is during solar maximum; during periods of moderate solar activity the best activity is found at low latitudes. The band offers useful short to medium range groundwave propagation, day or night. During the late spring and most of the summer, regardless of sunspot numbers, afternoon short band openings into small geographic areas of up to 1500 km occur due to Sporadic-E propagation. "Sporadic-E" is caused by areas of intense ionization in the E layer of the ionosphere. The causes of Sporadic-E are not fully understood, but these "clouds" of ionization can provide short term propagation from 17 meters all the way up to occasional 2 meter openings. FM operations are normally found at the high end of the band (Also repeaters are in the 29.5 - 29.7 MHz segment in a lot of countries).

Propagation Characteristics above HF

While "line of sight" propagation is a primary factor for range calculation, much of the interest in the bands above HF comes from use of other propagation modes. A VHF signal transmitted from a hand-held portable will typically travel about 5-10 km depending on terrain. With a low power home station and a simple antenna, range would be around 50 km. With a large antenna system like a long yagi, and higher power (typically 100 or more watts) contacts of around 1000 km using the CW (Morse code) and SSB (Single Side Band) modes are common. Ham operators seek to exploit the limits of the frequencies usual characteristics looking to learn, understand and experiment with the limits of these enhanced propagation modes. They also seek to take advantage of "band openings" where due to natural occurrences in the atmosphere and ionosphere radio transmission distances can extend well over their normal range. Many hams listen for hours hoping to take advantage of these occasional extended propagation 'openings'.

Some openings are caused by islands of intense ionization of the upper atmosphere known as the E Layer ionosphere. These islands of intense ionization are called 'Sporadic E' and result in erratic but often strong propagation characteristics on the 'low band' VHF radio frequencies. The 6 meter amateur band falls into this category, often called 'The Magic Band', 6 meters will often 'open up' from one small area into another small geographic area 1000–1700 km away during the spring and early summer months. This phenomenon occurs during the fall months, although not as often.

Band openings are sometimes caused by a weather phenomenon known as a tropospheric 'inversion', where a stagnant high pressure area causes alternating stratified layers of warm and cold air generally trapping the colder air beneath. This may make for smoggy/foggy days but it also causes VHF/UHF radio transmissions to travel or duct along the boundaries of these warm/cold atmospheric layers. Radio signals have been known to travel hundreds, even thousands of kilometers due to these unique weather conditions. For example: The longest distance reported contact due to tropospheric refraction on 2 meters is 4754 km between Hawaii and a ship south of Mexico. There were reports of the reception of one way signals from Réunion to Western Australia, a distance of more than 6000 km.[4]

F2 and TE band openings from other ionospheric reflection/refraction modes, or sky-wave propagation as it is known can also occasionally occur on the low band VHF frequencies of 6, 4 and very rarely on 2 meters (high band VHF) during extreme peaks in the 11 year sunspot cycle. The longest terrestrial contact ever reported on 2 meters (146mhz) was between a station in Italy and a station in South Africa, a distance of 7784 km, using anomalous enhancement (TE) of the ionosphere over the geomagnetic equator. This enhancement is known as TE, or trans-equatorial propagation and (usually) occurs at latitudes 2500–3000 km within either side of the equator.[5]

Other less frequently used modes are tropospheric scatter, moon bounce and Aurora Borealis (Northern Lights) and amateur radio satellite.

Using relatively high power, usually over 1000 watts and a high gain antenna, 'Tropo-scatter' (water droplets and dust particles can refract a VHF/UHF signal over the horizon) propagation will give marginal enhanced over-the-horizon VHF and UHF communications of up to 300 miles (450 km). During the 1970s commercial 'scatter site' operators using huge parabolic antennas and high power used this mode successfully for telephone communications services into remote Alaska and Canadian northern communities. Satellite, buried fiber optic and terrestrial microwave access have relegated Tropo-scatter to the history books. Because of high cost and complexity this mode is usually out of reach for the average amateur radio operator.

Moon Bounce: Using moderately high power (more than 500 watts) and a fairly large antenna, amateurs do successfully communicate by bouncing their signals off the surface of the moon. Round-trip path loss is on the order of 270dB for 70 cm signals. Return signals are weak and distorted because of the relative velocities of the transmitting station, moon and the receiving station. The moon's surface is also very rocky and irregular. Moon bounce communications use either digital modes, for example JT65, designed for working with weak signals, or CW Morse code.

Aurora: An intense solar storm causing aurora borealis (Northern Lights) will also provide occasional HF-low band 6 meter VHF propagation enhancement. Aurora only occasionally affects 2 meters. Signals are often distorted and on the lower frequencies give a curious 'watery sound' to normally propagated HF signals. Peak signals usually come from the north, even though the station you are talking to is east or west of you. Most noticeable in the northern latitudes above 45 degrees.

Satellite: Not really a propagation mode, but an active repeater system. Satellites have been highly successful in providing VHF/UHF/SHF users 'propagation' beyond the horizon. The ISS which has amateur radio repeaters and radio location services on board is a good example. Amateurs have also sponsored the launch of dozens of communications satellites since the 1970s. These satellites are usually known as OSCARs (Orbiting Satellite Carrying Amateur Radio).

Amateur television

Main article: Amateur television

Amateur television (ATV) is the hobby of transmitting broadcast- compatible video and audio by amateur radio. It also includes the study and building of such transmitters and receivers and the propagation between these two.

In NTSC countries, ATV operation requires the ability to use a 6 MHz wide channel. All bands at VHF or lower are less than 6 MHz wide, so ATV operation is confined to UHF and up. Bandwidth requirements will vary from this for PAL and SECAM transmissions.

ATV operation in the 70 cm band is particularly popular, because the signals can be received on any cable-ready television. Operation in the 33 cm and 23 cm bands is easily augmented by the availability of various varieties of consumer-grade wireless video devices that exist and operate in unlicensed frequencies coincident to these bands.

Repeater ATV operation requires specially-equipped repeaters.

See also slow-scan television.

Below the MW broadcast band

See also 500 kHz and 2200 meters

Historically, amateur stations have rarely been allowed to operate on frequencies lower than the medium-wave broadcast band, but in recent times, as the historic users of these low frequencies have been vacating the spectrum, limited space has opened up to allow for new amateur radio allocations and special experimental operations. Since the 500 kHz band is no longer used for marine communications, some countries permit experimental amateur radio radiotelegraph operations in that band. The 2200-meter band is available for use in several countries, and the 2007 World Radiocommunication Conference (WRC-07) made it a world wide amateur allocation. Before the introduction of the 2200-meter band in the UK in 1998, operation on the even lower frequency of 73 kHz had been allowed between 1996 and 2003.

ITU Region 1

ITU Region 1 corresponds to Europe, Russia, Africa and the Middle East. For ITU region 1, Radio Society of Great Britain's band plan [6] will be more definitive (click on the buttons at the bottom of the page).

- Low Frequency (LF) (30 to 300 kHz)
  - 2200 meters (135.7 kHz to 137.8 kHz)
- Very High Frequency (VHF) (30 to 300 MHz)
  - 4 metres (70 to 70.5 MHz), UK and some other ITU Region 1 countries

Table of Amateur MF and HF Bandplans

The following charts show the voluntary bandplans used by amateurs in Region 1. Unlike the USA, slots for the various transmission modes are not set by the amateur's license but most users do follow these guidelines.

160 Metres

See also: 160-meter band

160 Metres		1810 1838	1838 1840	1840 1843	1843 2000
IARU Region 1					
IARU Region 2	1800–1840				
IARU Region 3	1800–1840				
Note: Region 2 QRP/DX window is 1830-1850					

80 Metres

See also: 80-meter band

80 Metres	3500 3580	3580 3600	3600 3620	3620 3800
IARU Region 1				

60 Metres

60 Metres	5258.5		5278.5		5288.5		5366.5		5371.5		5398.5		5403.5
United Kingdom													
Note: 60 Meter emissions are limited to UK NoV-endorsed Full licence holders only in 3 kHz channels with the specified lower frequency limits, 200 watts Note: There are now 11 channels allocated in the UK, see the 60 Metres article for full details													

60 Metres - Norway and Denmark

60 Metres	start		5310.0		5335.0		5355.0		5375.0		5403.5		end
Norway Denmark	5260.0 5250.0		CW calling		QRP		Digimode		Nat. Call USB		Int. Call USB		5410.0 5450.0
Note: 60 Meter band in Norway is 5260 – 5410 kHz, in Denmark 5250 – 5450 kHz. **Danish stations have to apply for a special research-license and are limited to 1 kW ERP.** *Both countries can use VFO/allmode.*													

40 Metres

40 Metres	7000 7040	7040 7050	7050 7060	7060 7100	7100 7200	7200 7300
IARU Region 1						
As of March, 2009, 7100-7200 were allocated to Amateur radio on a primary basis by ITU. Yet, there are countries that haven't yet expanded their national Amateur radio service bandplan to cover that portion. In ITU region 2, 7200-7300 is allocated to amateur radio service as secondary.						

30 Metres

30 Metres	10100 10140	10140 10150
IARU Region 1		

20 Metres

20 Metres	14000 14070	14070 14099	B	14101 14350
IARU Region 1				

17 Metres

17 Metres	18068 18095	18095 18109	B	18111 18168
IARU Region 1				

15 Metres

15 Metres	21000 21070	21070 21110	21110 21120	21120 21149	B	21151 21450
IARU Region 1						

12 Metres

12 Metres	24890 24915	24915 24929	B	24931 24990
IARU Region 1				

10 Metres

10 Metres	28000 28070	28070 28190	B	28225 29200	29200 29300	29300 29510	29510 29700
IARU Region 1						Satellite D/L	

Key

= CW and data (<200 Hz bandwidth)

= CW, RTTY and data (< 500 Hz Bandwidth)

= CW, RTTY, data, NO SSB (<2.7 kHz)

= CW, phone and image (<3 kHz bandwidth) SECONDARY

= CW, phone and image (<3 kHz bandwidth)

= CW, data, packet, FM, phone and image (<20 kHz bandwidth)

= CW, RTTY, data, test, phone and image

= Reserved for satellite downlink

= Reserved for beacons

ITU Region 2

ITU region 2 consists of the Americas, including Greenland. The frequency allocations for United States hams in ITU Region 2 are:

ITU band	Band name	Frequencies (MHz)	
		Lower end	Upper end
5 - LF	2200 meters	135.7 kHz	137.8 kHz
6 - MF	160 meters	1.8 MHz	2.0 MHz
7 - HF	80 meters	3.5	4.0
	60 meters	*Channelized* - 5.332, 5.348, 5.358.5, 5.373, 5.405 MHz, modes see below [7])	
	40 meters	7.0	7.3
	30 meters	10.1	10.15
	20 meters	14	14.35
	17 meters	18.068	18.168
	15 meters	21	21.45
	12 meters	24.89	24.99
	10 meters	28	29.7
8 - VHF	6 meters	50	54
	2 meters	144	148
	1.25 meters	219	220
		222	225
9 - UHF	70 centimeters	420	450
	33 centimeters	902	928
	23 centimeters	1240	1300
	13 centimeters	2300	2310
		2390	2450

10 - SHF	9 centimeters	3300	3500
	5 centimeters	5650	5925
	3 centimeters	10000	10500
	1.2 centimeters	24000	24250
11 - EHF	6 millimeters	47000	47200
	4 millimeters	75500	81000
	2.5 millimeters	122500	123000
	2 millimeters	134000	141000
	1 millimeter	241000	250000

(ARRL 60-Meter Operations [7]

Regarding 60-meter band, Effective 5 March 2012 the FCC has permitted CW, USB, and certain digital modes on these frequencies. The National Telecommunications and Information Administration (NTIA) is the primary user of the 60-meter band. The FCC Report and Order permits the use of digital modes that comply with emission designator 60H0J2B, which includes PSK31 as well as any RTTY signal with a bandwidth of less than 60 Hz. The Report and Order also allows the use of modes that comply with emission designator 2K80J2D, which includes any digital mode with a bandwidth of 2.8 kHz or less whose technical characteristics have been documented publicly, per Part 97.309(4) of the FCC Rules. Such modes would include PACTOR I, II or III, 300-baud packet, MFSK, MT63, Contestia, Olivia, DominoEX and others. On 60 meters hams are restricted to only one signal per channel and automatic operation is not permitted. In addition, the FCC continues to require that all digital transmissions be centered on the channel-center frequencies, which the Report and Order defines as being 1.5 kHz above the suppressed carrier frequency of a transceiver operated in the Upper Sideband (USB) mode. As amateur radio equipment displays the carrier frequency, it is important for operators to understand correct frequency calculations for digital "sound-card" modes to ensure compliance with the channel-center requirement.

The ARRL has a detailed band plan [8] for US hams showing allocations within each band.

RAC has a chart showing the frequencies available to amateurs in Canada [9].

Table of Amateur MF and HF Allocations in the United States and Canada

160 m	1800–2000
Canada	
United States	1800 2000
General, Advanced, Extra	

80 / 75 m	3500 - 4000				
Canada					
United States	3500 3525	3525 3600	3600 3700	3700 3800	3800 4000
Novice / Technician					
General					
Advanced					
Extra					

60 m	5330 - 5406												
United States	5330.5		5346.5		5357.0		5371.5		5403.5				
General, Advanced, Extra													
Note: US licensees operating 60 m are limited to 100 watts PEP ERP relative to a 1/2 wave dipole, on the carrier frequencies indicated on this chart													

40 m	7000 - 7300			
Canada				
United States	7000 7025	7025 7125	7125 7175	7175 7300
Novice / Technician				
General				
Advanced				
Extra				

30 m	10100 10150
Canada	
United States	
Note: US limited to General, Advanced and Extra **licensees; 200 watts PEP**	

20 m	14000 - 14350				
Canada					
United States	14000 14025	14025 14150	14150 14175	14175 14225	14225 14350
General					
Advanced					
Extra					

17 m	18068 - 18168	
Canada		
United States	18068 18110	18110 18168
General, Advanced, Extra		

15 m	21000 - 21450				
Canada					
United States	21000 21025	21025 21200	21200 21225	21225 21275	21275 21450
Novice / Technician					
General					
Advanced					
Extra					

12 m	24890 - 24990	
Canada		
United States	24890 24930	24930 24990
General, Advanced, Extra		

10 m	28000 - 29700		
Canada			
United States	28000 28300	28300 28500	28500 29700
Novice / Technician			
General, Advanced, Extra			
Note: The 10 meter table is one-third scale, relative to the other tables			

Key

= CW, RTTY and data (US: < 1 kHz Bandwidth)

= CW, RTTY, data, MCW, phone (AM and SSB) and image (narrow band sstv modes only)

= CW, phone and image

= CW and SSB phone (US: Novice/Technician 200 watts PEP only)

= CW, RTTY, data, phone and image

= CW (US: Novice/Technician 200 watts PEP only)

= CW, Upper sideband suppressed carrier phone, 2.8 kHz bandwidth (2K80J3E) data (60H0J2B and 2K80J2D), 100 watts ERP referenced to 1/2 wave dipole

= CW, RTTY and data (US: < 1 kHz Bandwidth, Novice/Technician 200 watts PEP)

ITU Region 3

ITU region 3 consists of Australia, Indonesia, Japan, New Zealand, the South Pacific, and Asia south of Siberia. The IARU frequency allocations for hams in ITU Region 3 are:

The Region 3 Bandplan [10] is as follows:

ITU band	Band name	Frequencies (MHz)	
		Lower end	Upper end
5 - LF	2200 meters	135.7 kHz	137.8 kHz
6 - MF	630 meters	472 kHz	479 kHz
	160 meters	1.8	2.0
7 - HF	80 meters	3.5	3.9
	40 meters	7.0	7.3
	30 meters	10.1	10.157.3
	20 meters	14	14.35
	17 meters	18.068	18.168
	15 meters	21	21.45
	12 meters	24.89	24.99
	10 meters	28	29.7
8 - VHF	6 meters	50	54
	2 meters	144	148
9 - UHF	70 centimeters	430	450
	23 centimeters	1240	1300

Bands above 1300 MHz: Societies should consult with the amateur satellite community for proposed satellite operating frequencies before deciding local bandplans above 1300 MHz.

Not all Member Unions follow this plan. As an example, the ACMA does not allow Australian Amateurs to use 3.700 MHz to 3.768 MHz and 3.800 MHz to 3.900 MHz, allocating this region to Emergency and Ambulatory services (Allocations can be found conducting a search of the ACMA Radcomms register [11].)

The Wireless Institute of Australia has charts for Amateur frequencies for Australia. [12]

The New Zealand Association of Radio Transmitters (NZART) has charts for Amateur frequencies and repeater lists for New Zealand. [13]

The Japanese have charts for Amateur frequencies in Japan [14]

Space Operations

See also: amateur radio satellite

Radio amateurs may engage in satellite and space craft communications; however, the frequencies allowed for such activities are allocated separately from more general use radio amateur bands.

Under the International Telecommunication Union's rules, all amateur radio operations may only occur within 50 kilometres (31 mi) of the Earth's surface. As such, the *Amateur Radio Service* is not permitted to engage in satellite operations; however, a sister radio service, called the **Amateur Satellite Service**, exists which allows satellite operations for the same purposes as the *Amateur Radio Service*. In most countries, an amateur radio license conveys operating privileges in both services, and in practice, the legal distinction between the two services is transparent to the average licensee. The primary reason the two services are separate is to limit the frequencies available for satellite operations. Due to the shared nature of the amateur radio allocations internationally, and the nature of satellites to roam worldwide, the ITU does not consider all amateur radio bands appropriate for satellite operations. Being separate from the *Amateur Radio Service*, the *Amateur Satellite Service* receives its own frequency allocations. All the allocations are within amateur radio bands, and with one exception, the allocations are the same in all three ITU regions. Some of the allocations are limited by the ITU in what direction transmissions may be sent (EG: "Earth-to-space" or up-links only).

All amateur satellite operations occur within the allocations tabled below, except for AO-7, which has an up-link from 432.125 MHz to 432.175 MHz.

International amateur satellite frequency allocations

Range	Band	Letter[1]	Allocation	Preferred sub-bands[2]	User status	Notes
HF	**40 m**		7.000 MHz - 7.100 MHz		Primary	
	20 m		14.000 MHz - 14.250 MHz		Primary	
	17 m		18.068 MHz - 18.168 MHz		Primary	Entire amateur radio band
	15 m	H	21.000 MHz - 21.450 MHz		Primary	Entire amateur radio band
	12 m		24.890 MHz - 25.990 MHz		Primary	Entire amateur radio band
	10 m	A	28.000 MHz - 29.700 MHz	29.300 MHz - 29.510 MHz	Primary	Entire amateur radio band
VHF	**2 m**	V	144.000 MHz - 146.000 MHz	145.800 MHz - 146.000 MHz	Primary	
UHF	**70 cm**	U	435.000 MHz - 438.000 MHz		NIB[3]	
	23 cm	L	1.260 GHz - 1.270 GHz		NIB[3]	Only uplinks allowed
	13 cm	S	2.400 GHz - 2.450 GHz	2.400 GHz - 2.403 GHz	NIB[3]	
SHF	**9 cm**	S2	3.400 GHz - 3.410 GHz		NIB[3]	Not available in ITU region 1.
	5 cm	C	5.650 GHz - 5.670 GHz		NIB[3]	Only uplinks allowed
			5.830 GHz - 5.850 GHz		Secondary	Only downlinks allowed
	3 cm	X	10.450 GHz - 10.500 GHz		Secondary	
	1.2 cm	K	24.000 GHz - 24.050 GHz		Primary	
EHF[4]	**6 mm**	R	47.000 GHz - 47.200 GHz		Primary	Entire amateur radio band
	4 mm		76.000 GHz - 77.500 GHz		Secondary	
			77.500 GHz - 78.000 GHz		Primary	
			78.000 GHz - 81.000 GHz		Secondary	
	2 mm		134.000 GHz - 136.000 GHz		Primary	Entire amateur radio band
			136.000 GHz - 141.000 GHz		Secondary	
	1 mm		241.000 GHz - 248.000 GHz		Secondary	Entire amateur radio band
			248.000 GHz - 250.000 GHz		Primary	

[1] AMSAT band letters. Not all bands have been assigned a letter by AMSAT.
[2] For some allocations, satellite operations are predominately concentrated in a sub-band of the allocation.
[3] Footnote allocation. Use is only allowed on a non-interference basis to other users, as per ITU footnote 5.282.
[4] No amateur satellite operations have yet occurred at EHF; however, AMSAT's P3E is planned to have an R band down-link.

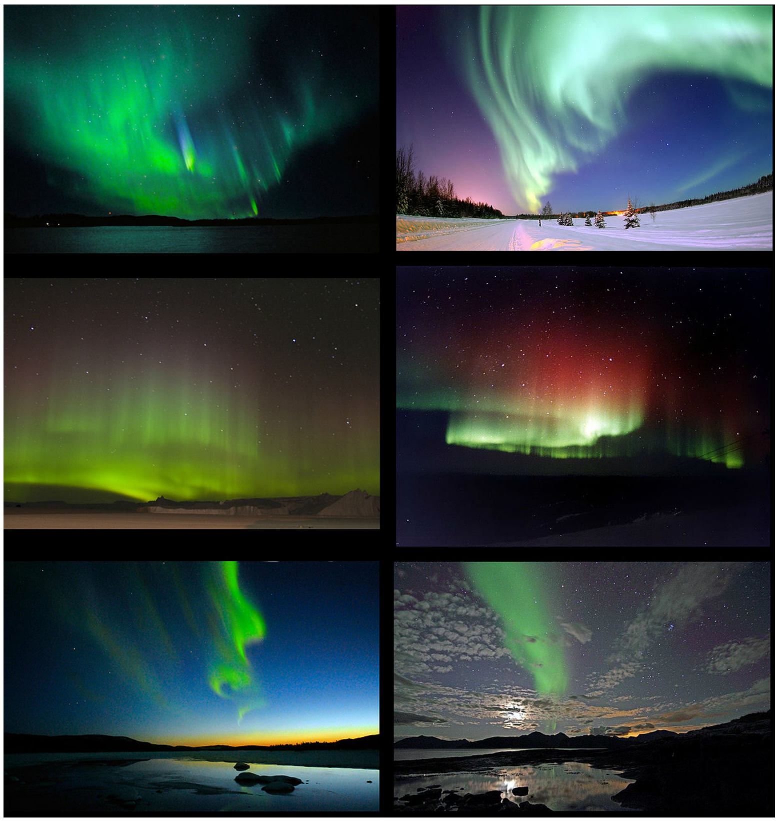
References

[1] http://en.wikipedia.org/w/index.php?title=Template:Amateur_radio&action=edit
[2] http://life.itu.int/radioclub/rr/hfband.htm
[3] Larry D. Wolfgang et al., (ed), The ARRL Handbook for Radio Amateurs, Sixty-Eighth Edition , (1991), ARRL, Newington CT USA ISBN 0-87259-168-9 Chapter 37
[4] http://df5ai.net/ArticlesDL/HadleyCellProp.pdf
[5] http://sektion-vhf.ssa.se/dxrecord/dxrec.htm
[6] http://www.rsgb.org/spectrumforum/bandplans/RSGB%20Band%20Plan%20master.htm
[7] http://www.arrl.org/files/file/Regulatory/Recommended_Practices_Version_6_5.pdf
[8] http://www.arrl.org/FandES/field/regulations/bandplan.html
[9] http://www.rac.ca/regulatory/allband.htm
[10] http://www.jarl.or.jp/iaru-r3/
[11] http://web.acma.gov.au/pls/radcom/register_search.main_page
[12] http://www.wia.org.au/members/bandplans/data/
[13] http://www.nzart.org.nz/maps/index.html
[14] http://www.jarl.or.jp/English/6_Band_Plan/JapaneseAmateurBandplans20090330.pdf

Aurora

See also Aurora (disambiguation), Aurora Australis (disambiguation), or Aurora Borealis (disambiguation).

An **aurora** is a natural light display in the sky (from the Latin word *aurora*, "sunrise" or the Roman goddess of dawn), especially in the high latitude (Arctic and Antarctic) regions, caused by the collision of solar wind and magnetospheric charged particles with the high altitude atmosphere (thermosphere). Most auroras occur in a band known as the *auroral zone*, which is typically 3° to 6° wide in latitude and observed at 10° to 20° from the geomagnetic poles at all local times (or longitudes), but often most vividly around the spring and autumn equinoxes. The charged particles and solar wind are directed into the atmosphere by the Earth's magnetosphere. A geomagnetic storm expands the auroral zone to lower latitudes.



Images of the aurora australis and aurora borealis from around the world, including those with rarer red and blue lights

Overview

Auroras or aurorae[1] are classified as diffuse and discrete. The diffuse aurora is a featureless glow in the sky that may not be visible to the naked eye, even on a dark night. It defines the extent of the auroral zone. The discrete auroras are sharply defined features within the diffuse aurora that vary in brightness from just barely visible to the naked eye, to bright enough to read a newspaper by at night. Discrete auroras are usually seen in only the night sky, because they are not as bright as the sunlit sky. Auroras occasionally occur poleward of the auroral zone as diffuse patches or arcs, which are generally subvisual.

In northern latitudes, the effect is known as the ***aurora borealis*** (or the **northern lights**), named after the Roman goddess of dawn, Aurora, and the Greek name for the north wind, Boreas, by Galileo in 1619.[2] Auroras seen near the magnetic pole may be high overhead, but from farther away, they illuminate the northern horizon as a greenish glow or sometimes a faint red, as if the Sun were rising from an unusual direction. Discrete auroras often display magnetic field lines or curtain-like structures, and can change within seconds or glow unchanging for hours, most often in fluorescent green. The aurora borealis most often occurs near the equinoxes. The northern lights have had a number of names throughout history. The Cree call this phenomenon the "**Dance of the Spirits**". In Medieval Europe, the auroras were commonly believed to be a sign from God.[3]

Its southern counterpart, the ***aurora australis*** (or the **southern lights**), has features that are almost identical to the aurora borealis and changes simultaneously with changes in the northern auroral zone. It is visible from high southern latitudes in Antarctica, South America, New Zealand, and Australia. Auroras occur on other planets. Similar to the Earth's aurora, they are visible close to the planet's magnetic poles. Modern style guides recommend that the names of meteorological phenomena, such as *aurora borealis*, be uncapitalized.

Video of the aurora australis taken by the crew of Expedition 28 on board the International Space Station, its sequence of shots was taken 17 September 2011 from 17:22:27 to 17:45:12 GMT, on an ascending pass from south of Madagascar to just north of Australia over the Indian Ocean

Video of the aurora australis taken by the crew of Expedition 28 on board the International Space Station, its sequence of shots was taken 7 September 2011 from 17:38:03 to 17:49:15 GMT, from the French Southern and Antarctic Lands in the South Indian Ocean to southern Australia

Video of the aurora australis taken by the crew of Expedition 28 on board the International Space Station, its sequence of shots was taken 11 September 2011 from 13:45:06 to 14:01:51 GMT, from a descending pass near eastern Australia, rounding about to an ascending pass to the east of New Zealand

History of aurora theories

Multiple superstitions and obsolete theories explaining the aurora have surfaced over the centuries.

- Seneca speaks diffusely on auroras in the first book of his Naturales Quaestiones, drawing mainly from Aristotle; he classifies them "putei" or wells when they are circular and "rim a large hole in the sky", "pithaei" when they look like casks, "chasmata" from the same root of the English chasm, "pogoniae" when they are bearded, "cyparissae" when they look like cypresses), describes their manifold colors and asks himself whether they are above or below the clouds. He recalls that under Tiberius, an aurora formed above Ostia, so intense and so red that a cohort of the army, stationed nearby for fireman duty, galloped to the city.
- Walter William Bryant wrote in his book *Kepler* (1920) that Tycho Brahe "seems to have been something of a homœopathist, for he recommends sulfur to cure infectious diseases “brought on by the sulphurous vapours of the Aurora Borealis."[4]
- Benjamin Franklin theorized that the "mystery of the Northern Lights" was caused by a concentration of electrical charges in the polar regions intensified by the snow and other moisture.
- Auroral electrons come from beams emitted by the Sun. This was claimed around 1900 by Kristian Birkeland, whose experiments in a vacuum chamber with electron beams and magnetized spheres (miniature models of Earth or "terrellas") showed that such electrons would be guided toward the polar regions. Problems with this model included absence of aurora at the poles themselves, self-dispersal of such beams by their negative charge, and more recently, lack of any observational evidence in space.
- The aurora is the overflow of the radiation belt ("leaky bucket theory"). This was first disproved around 1962 by James Van Allen and co-workers, who showed that the high rate of energy dissipation by the aurora would quickly drain the radiation belt. Soon afterward, it became clear that most of the energy in trapped particles resided in positive ions, while auroral particles were almost always electrons, of relatively low energy.
- The aurora is produced by solar wind particles guided by Earth's field lines to the top of the atmosphere. This holds true for the cusp aurora, but outside the cusp, the solar wind has no direct access. In addition, the main energy in the solar wind resides in positive ions; electrons only have about 0.5 eV (electron volt), and while in the cusp this may be raised to 50–100 eV, that still falls short of auroral energies.

Auroral mechanism

Auroras are associated with the solar wind, a flow of ions continuously flowing outward from the Sun. The Earth's magnetic field traps these particles, many of which travel toward the poles where they are accelerated toward Earth. Collisions between these ions and atmospheric atoms and molecules cause energy releases in the form of auroras appearing in large circles around the poles. Auroras are more frequent and brighter during the intense phase of the solar cycle when coronal mass ejections increase the intensity of the solar wind.

Auroras result from emissions of photons in the Earth's upper atmosphere, above 80 km (50 mi), from ionized nitrogen molecules regaining an electron, and oxygen atoms and nitrogen molecules returning from an excited state to ground state. They are ionized or excited by the collision of solar wind and magnetospheric particles being funneled down and accelerated along the Earth's magnetic field lines; excitation energy is lost by the emission of a photon, or by collision with another atom or molecule:

oxygen emissions

: green or orange-red, depending on the amount of energy absorbed.

nitrogen emissions

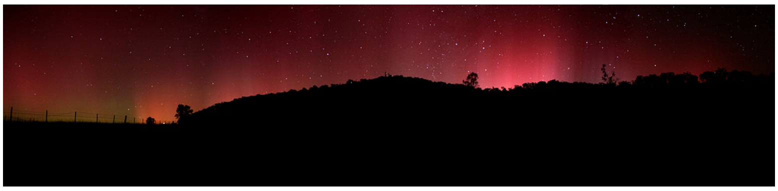
: blue or red; blue if the atom regains an electron after it has been ionized, red if returning to ground state from an excited state.

Oxygen is unusual in terms of its return to ground state: it can take three quarters of a second to emit green light and up to two minutes to emit red. Collisions with other atoms or molecules absorb the excitation energy and prevent emission. Because the very top of the atmosphere has a higher percentage of oxygen and is sparsely distributed such collisions are rare enough to allow time for oxygen to emit red. Collisions become more frequent progressing down into the atmosphere, so that red emissions do not have time to happen, and eventually even green light emissions are prevented.

This is why there is a color differential with altitude; at high altitude oxygen red dominates, then oxygen green and nitrogen blue/red, then finally nitrogen blue/red when collisions prevent oxygen from emitting anything. Green is the most common of all auroras. Behind it is pink, a mixture of light green and red, followed by pure red, yellow (a mixture of red and green), and finally, pure blue.

Auroral colors

- **Red**: At the highest altitudes, excited atomic oxygen emits at 630.0 nm (red); low concentration of atoms and lower sensitivity of eyes at this wavelength make this color visible only under some circumstances with more intense solar activity. The low amount of oxygen atoms and their very gradually diminishing concentration is responsible for the faint, gradual appearance of the top parts of the "curtains".
- **Green**: At lower altitudes the more frequent collisions suppress this mode and the 557.7 nm emission (green) dominates; fairly high concentration of atomic oxygen and higher eye sensitivity in green make green auroras the most common. The excited molecular nitrogen (atomic nitrogen being rare due to high stability of the N_2 molecule) plays its role here as well, as it can transfer energy by collision to an oxygen atom, which then radiates it away at the green wavelength. (Red and green can also mix together to pink or yellow hues.) The rapid decrease of concentration of atomic oxygen below about 100 km is responsible for the abrupt-looking end of the bottom parts of the curtains.
- **Yellow** and **pink** are a mix of red and green or blue.
- **Blue**: At yet lower altitudes atomic oxygen is not common anymore, and ionized molecular nitrogen takes over in visible light emission; it radiates at a large number of wavelengths in both red and blue parts of the spectrum, with 428 nm (blue) being dominant. Blue and purple emissions, typically at the bottoms of the "curtains", show up at the highest levels of solar activity.



A predominantly red aurora australis

Forms and magnetism

The aurora appears frequently either as a diffuse glow or as "curtains" that approximately extend in the east-west direction. At some times, they form "quiet arcs"; at others ("active aurora"), they evolve and change constantly. Each curtain consists of many parallel rays, each lined up with the local direction of the magnetic field lines, suggesting that auroras are shaped by Earth's magnetic field. Indeed, satellites show that electrons are guided by magnetic field lines, spiraling around them while moving toward Earth.

Aurora timelapse video (40 minutes)

The similarity to curtains is often enhanced by folds called "striations". When the field line guiding a bright auroral patch leads to a point directly above the observer, the aurora may appear as a "corona" of diverging rays, an effect of perspective.

Northern lights over Calgary

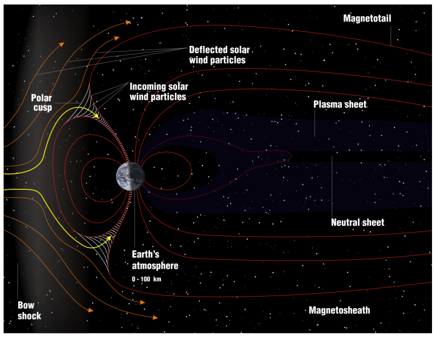
Although it was first mentioned by Ancient Greek explorer/geographer Pytheas, Hiorter and Celsius first described in 1741 evidence for magnetic control, namely, large magnetic fluctuations occurred whenever the aurora was observed overhead. This indicates (it was later realized) that large electric currents were associated with the aurora, flowing in the region where auroral light originated. Kristian Birkeland (1908)[5] deduced that the currents flowed in the east-west directions along the auroral arc, and such currents, flowing from the dayside toward (approximately) midnight were later named "auroral electrojets" (see also Birkeland currents).

Still more evidence for a magnetic connection are the statistics of auroral observations. Elias Loomis (1860) and later in more detail Hermann Fritz (1881)[6] and S. Tromholt (1882)[7] established that the aurora appeared mainly in the "auroral zone", a ring-shaped region with a radius of approximately 2500 km around Earth's magnetic pole. It was hardly ever seen near the geographic pole, which is about 2000 km away from the magnetic pole. The instantaneous distribution of auroras ("auroral oval") is slightly different, centered about 3–5 degrees nightward of the magnetic pole, so that auroral arcs reach furthest toward the equator when the magnetic pole in question is in between the observer and the Sun. The aurora can be seen best at this time, called magnetic midnight.

In the 1970s, astrophysicist Joan Feynman deduced that auroras are a product of the interaction between the Earth's magnetosphere and the magnetic field of the solar wind. Her work resulted from data collected by the Explorer 33 spacecraft.

On 26 February 2008, THEMIS probes were able to determine, for the first time, the triggering event for the onset of magnetospheric substorms. Two of the five probes, positioned approximately one third the distance to the moon, measured events suggesting a magnetic reconnection event 96 seconds prior to auroral intensification. Dr. Vassilis Angelopoulos of the University of California, Los Angeles, the principal investigator for the THEMIS mission, claimed, "Our data show clearly and for the first time that magnetic reconnection is the trigger."

Solar wind and the magnetosphere



Schematic of Earth's magnetosphere

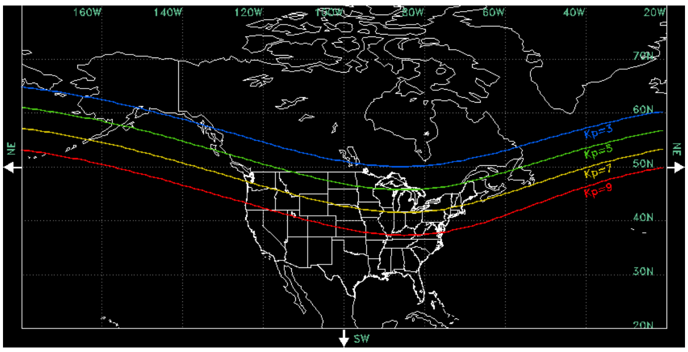
The Earth is constantly immersed in the solar wind, a rarefied flow of hot plasma (gas of free electrons and positive ions) emitted by the Sun in all directions, a result of the two-million-degree heat of the Sun's outermost layer, the corona. The solar wind usually reaches Earth with a velocity around 400 km/s, density around 5 ions/cm^3 and magnetic field intensity around 2–5 nT (nanoteslas; Earth's surface field is typically 30,000–50,000 nT). These are typical values. During magnetic storms, in particular, flows can be several times faster; the interplanetary magnetic field (IMF) may also be much stronger.

The IMF originates on the Sun, related to the field of sunspots, and its field lines (lines of force) are dragged out by the solar wind. That alone would tend to line them up in the Sun-Earth direction, but the rotation of the Sun skews them (at Earth) by about 45 degrees, so that field lines passing Earth may actually start near the western edge ("limb") of the visible Sun.[8]

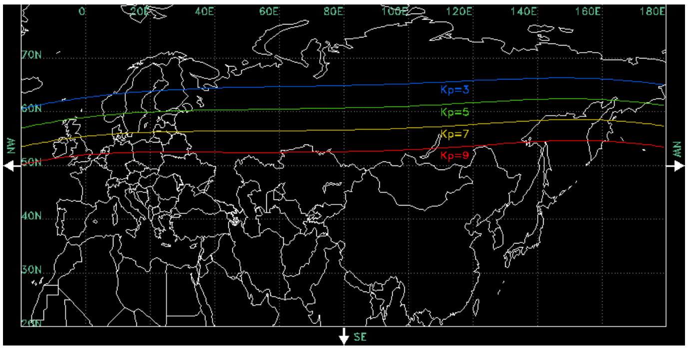
Earth's magnetosphere is formed by the impact of the solar wind on the Earth's magnetic field. It forms an obstacle to the solar wind, diverting it, at an average distance of about 70,000 km (11 Earth radii or Re), forming a bow shock 12,000 km to 15,000 km (1.9 to 2.4 Re) further upstream. The width of the magnetosphere abreast of Earth, is typically 190,000 km (30 Re), and on the night side a long "magnetotail" of stretched field lines extends to great distances (> 200 Re).

The magnetosphere is full of trapped plasma as the solar wind passes the Earth. The flow of plasma into the magnetosphere increases with increases in solar wind density and speed, with increase in the southward component of the IMF and with increases in turbulence in the solar wind flow. The flow pattern of magnetospheric plasma is from the magnetotail toward the Earth, around the Earth and back into the solar wind through the magnetopause on the day-side. In addition to moving perpendicular to the Earth's magnetic field, some magnetospheric plasma travel down along the Earth's magnetic field lines and lose energy to the atmosphere in the auroral zones. Magnetospheric electrons accelerated downward by field-aligned electric fields cause the bright aurora features. The un-accelerated electrons and ions cause the dim glow of the diffuse aurora.

Frequency of occurrence



North America



Eurasia

These NOAA maps of North America and Eurasia show the local midnight equatorward boundary of the aurora at different levels of geomagnetic activity; a Kp=3 corresponds to low levels of geomagnetic activity, while Kp=9 represents high levels

Auroras are occasionally seen in temperate latitudes, when a magnetic storm temporarily enlarges the auroral oval. Large magnetic storms are most common during the peak of the eleven-year sunspot cycle or during the three years after that peak. Within the auroral zone the likelihood of an aurora occurring depends mostly on the slant of interplanetary magnetic field (IMF) lines (the slant is known as B_z), however, being greater with southward slants.

Geomagnetic storms that ignite auroras actually happen more often during the months around the equinoxes. It is not well understood why geomagnetic storms are tied to Earth's seasons while polar activity is not. But it is known that during spring and autumn, the interplanetary magnetic field and that of Earth link up. At the magnetopause, Earth's magnetic field points north. When B_z becomes large and negative (i.e., the IMF tilts south), it can partially cancel Earth's magnetic field at the point of contact. South-pointing B_zs open a door through which energy from the solar wind reaches Earth's inner magnetosphere.

The peaking of B_z during this time is a result of geometry. The IMF comes from the Sun and is carried outward with the solar wind. The rotation of the Sun causes the IMF to have a spiral shape called the Parker spiral. The southward (and northward) excursions of B_z are greatest during April and October, when Earth's magnetic dipole axis is most closely aligned with the Parker spiral.

B_z is not the only influence on geomagnetic activity, however, the Sun's rotation axis is tilted 8 degrees with respect to the plane of Earth's orbit. The solar wind blows more rapidly from the Sun's poles than from its equator, thus the average speed of particles buffeting Earth's magnetosphere waxes and wanes every six months. The solar wind speed is greatest – by about 50 km/s, on average – around 5 September and 5 March when Earth lies at its highest heliographic latitude.

Still, neither B_z nor the solar wind can fully explain the seasonal behavior of geomagnetic storms. Those factors together contribute only about one-third of the observed semiannual variations.

Auroral events of historical significance

The auroras that resulted from the "great geomagnetic storm" on both 28 August and 2 September 1859 are thought the most spectacular in recent recorded history. In a paper to the Royal Society on 21 November 1861, Scottish physicist Balfour Stewart described both auroral events as documented by a self-recording magnetograph at the Kew Observatory and established the connection between the 2 September 1859 auroral storm and the Carrington-Hodgson flare event when he observed that, "It is not impossible to suppose that in this case our luminary was taken *in the act*." The second auroral event, which occurred on 2 September 1859 as a result of the exceptionally intense Carrington-Hodgson white light solar flare on 1 September 1859, produced auroras so widespread and extraordinarily brilliant that they were seen and reported in published scientific measurements, ship logs, and newspapers throughout the United States, Europe, Japan, and Australia. It was reported by the *New York Times*[9][10][11] that in Boston on Friday 2 September 1859 the aurora was "so brilliant that at about one o'clock ordinary print could be read by the light".[12] One o'clock EST time on Friday 2 September, would have been 6:00 GMT and the self-recording magnetograph at the Kew Observatory was recording the geomagnetic storm, which was then one hour old, at its full intensity. Between 1859 and 1862, Elias Loomis published a series of nine papers on the Great Auroral Exhibition of 1859 in the *American Journal of Science* where he collected world-wide reports of the auroral event.

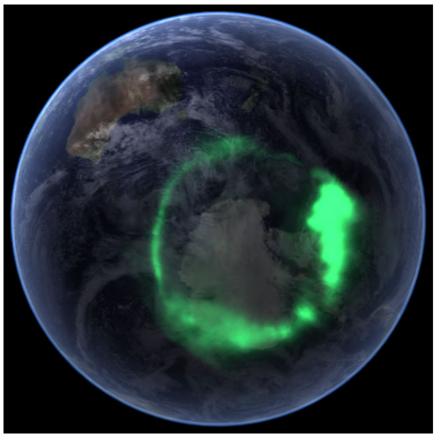
The aurora is thought to have been produced by one of the most intense coronal mass ejections in history, very near the maximum intensity that the Sun is thought capable of producing. It is also notable for the fact that it is the first time where the phenomena of auroral activity and electricity were unambiguously linked. This insight was made possible not only due to scientific magnetometer measurements of the era, but also as a result of a significant portion of the 125,000 miles (201,000 km) of telegraph lines then in service being significantly disrupted for many hours throughout the storm. Some telegraph lines, however, seem to have been of the appropriate length and orientation to produce a sufficient geomagnetically induced current from the electromagnetic field to allow for continued communication with the telegraph operator power supplies switched off. The following conversation occurred between two operators of the American Telegraph Line between Boston and Portland, Maine, on the night of 2 September 1859 and reported in the *Boston Traveler*:

> **Boston operator (to Portland operator):** "Please cut off your battery [power source] entirely for fifteen minutes."
>
> **Portland operator:** "Will do so. It is now disconnected."
>
> **Boston:** "Mine is disconnected, and we are working with the auroral current. How do you receive my writing?"
>
> **Portland:** "Better than with our batteries on. – Current comes and goes gradually."
>
> **Boston:** "My current is very strong at times, and we can work better without the batteries, as the aurora seems to neutralize and augment our batteries alternately, making current too strong at times for our relay magnets. Suppose we work without batteries while we are affected by this trouble."
>
> **Portland:** "Very well. Shall I go ahead with business?"
>
> **Boston:** "Yes. Go ahead."

The conversation was carried on for around two hours using no battery power at all and working solely with the current induced by the aurora, and it was said that this was the first time on record that more than a word or two was transmitted in such manner. Such events led to the general conclusion that

> The effect of the aurorae on the electric telegraph is generally to increase or diminish the electric current generated in working the wires. Sometimes it entirely neutralizes them, so that, in effect, no fluid is discoverable in them. The aurora borealis seems to be composed of a mass of electric matter, resembling in every respect, that generated by the electric galvanic battery. The currents from it change coming on the wires, and then disappear: the mass of the aurora rolls from the horizon to the zenith.[13]

Origin



Aurora australis (11 September 2005) as captured by NASA's IMAGE satellite, digitally overlaid onto *The Blue Marble* composite image An animation created using the same satellite data is also available

The ultimate energy source of the aurora is the solar wind flowing past the Earth. The magnetosphere and solar wind consist of plasma (ionized gas), which conducts electricity. It is well known (since Michael Faraday's work around 1830) that when an electrical conductor is placed within a magnetic field while relative motion occurs in a direction that the conductor cuts *across* (or is cut *by*), rather than *along*, the lines of the magnetic field, an electric current is said to be induced into that conductor and electrons flow within it. The amount of current flow is dependent upon a) the rate of relative motion, b) the strength of the magnetic field, c) the number of conductors ganged together and d) the distance between the conductor and the magnetic field, while the *direction* of flow is dependent upon the direction of relative motion. Dynamos make use of this basic process ("the dynamo effect"), any and all conductors, solid or otherwise are so affected including plasmas or other fluids.

In particular the solar wind and the magnetosphere are two electrically conducting fluids with such relative motion and should be able (in principle) to generate electric currents by "dynamo action", in the process also extracting energy from the flow of the solar wind. The process is hampered by the fact that plasmas conduct easily along magnetic field lines, but not so easily perpendicular to them. So it is important that a temporary magnetic connection be established between the field lines of the solar wind and those of the magnetosphere, by a process known as magnetic reconnection. It happens most easily with a southward slant of interplanetary field lines, because then field lines north of Earth approximately match the direction of field lines near the north magnetic pole (namely, *into* Earth), and similarly near the south magnetic pole. Indeed, active auroras (and related "substorms") are much more likely at such times. Electric currents originating in such way apparently give auroral electrons their energy. The magnetospheric plasma has an abundance of electrons: some are magnetically trapped, some reside in the magnetotail, and some exist in the upward extension of the ionosphere, which may extend (with diminishing density) some 25,000 km around Earth.

Bright auroras are generally associated with Birkeland currents (Schield et al., 1969; Zmuda and Armstrong, 1973) which flow down into the ionosphere on one side of the pole and out on the other. In between, some of the current connects directly through the ionospheric E layer (125 km); the rest ("region 2") detours, leaving again through field lines closer to the equator and closing through the "partial ring current" carried by magnetically trapped plasma. The ionosphere is an ohmic conductor, so such currents require a driving voltage, which some dynamo mechanism can supply. Electric field probes in orbit above the polar cap suggest voltages of the order of 40,000 volts, rising up to more than 200,000 volts during intense magnetic storms.

Ionospheric resistance has a complex nature, and leads to a secondary Hall current flow. By a strange twist of physics, the magnetic disturbance on the ground due to the main current almost cancels out, so most of the observed effect of auroras is due to a secondary current, the auroral electrojet. An auroral electrojet index (measured in nanotesla) is regularly derived from ground data and serves as a general measure of auroral activity.

Ohmic resistance is not the only obstacle to current flow in this circuit, however, the convergence of magnetic field lines near Earth creates a "mirror effect" that turns back most of the down-flowing electrons (where currents flow upward), inhibiting current-carrying capacity. To overcome this, part of the available voltage appears along the field line ("parallel to the field"), helping electrons overcome that obstacle by widening the bundle of trajectories reaching Earth; a similar "parallel potential" is used in "tandem mirror" plasma containment devices. A feature of such voltage is that it is concentrated near Earth (potential proportional to field intensity; Persson, 1963), and indeed, as deduced by Evans (1974) and confirmed by satellites, most auroral acceleration occurs below 10,000 km. Another indicator of parallel electric fields along field lines are beams of upward flowing O+ ions observed on auroral field lines.

ISS Expedition 6 team, Lake Manicouagan is visible to the bottom left

Some O+ ions ("conics") also seem accelerated in different ways by plasma processes associated with the aurora. These ions are accelerated by plasma waves, in directions mainly perpendicular to the field lines. They therefore start at their own "mirror points" and can travel only upward. As they do so, the "mirror effect" transforms their directions of motion, from perpendicular to the line to lying on a cone around it, which gradually narrows down.

In addition, the aurora and associated currents produce a strong radio emission around 150 kHz known as auroral kilometric radiation (AKR, discovered in 1972). Ionospheric absorption makes AKR observable from space only.

These "parallel potentials" accelerate electrons to auroral energies and seem to be a major source of aurora. Other mechanisms have also been proposed, in particular, Alfvén waves, wave modes involving the magnetic field first noted by Hannes Alfvén (1942), which have been observed in the lab and in space. The question is whether these waves might just be a different way of looking at the above process, however, because this approach does not point out a different energy source, and many plasma bulk phenomena can also be described in terms of Alfvén waves.

Other processes are also involved in the aurora, and much remains to be learned. Auroral electrons created by large geomagnetic storms often seem to have energies below 1 keV, and are stopped higher up, near 200 km. Such low energies excite mainly the red line of oxygen, so that often such auroras are red. On the other hand, positive ions also reach the ionosphere at such time, with energies of 20–30 keV, suggesting they might be an "overflow" along magnetic field lines of the copious "ring current" ions accelerated at such times, by processes different from the ones described above.

Sources and types

Our scientific understanding of auroras' causes is very incomplete. There are three possible main sources:

1. Dynamo action with the solar wind *flowing past Earth*, possibly producing quiet auroral arcs ("directly driven" process). The circuit of the accelerating currents and their connection to the solar wind are uncertain.
2. Dynamo action involving plasma squeezed toward Earth by sudden convulsions of the magnetotail ("magnetic substorms"). Substorms tend to occur after prolonged spells (hours) during which the interplanetary magnetic field has an appreciable southward component, leading to a high rate of interconnection between its field lines and those of Earth. As a result the solar wind moves magnetic flux (tubes of magnetic field lines, moving together with their resident plasma) from the day side of Earth to the magnetotail, widening the obstacle it presents to the solar wind flow and causing it to be squeezed harder. Ultimately the tail plasma is torn ("magnetic reconnection"); some blobs ("plasmoids") are squeezed tailward and are carried away with the solar wind; others are squeezed toward Earth where their motion feeds large outbursts of aurora, mainly around midnight ("unloading process"). Geomagnetic storms have similar effects, but with greater vigor. The big difference is the addition of many particles to the plasma trapped around Earth, enhancing the "ring current" it carries. The resulting modification of Earth's field makes auroras visible at middle latitudes, on field lines much closer to the equator.
3. Satellite images of the aurora from above show a "ring of fire" along the auroral oval (see above), often widest at midnight. That is the "diffuse aurora", not distinct enough to see with the eye. It does *not* seem associated with acceleration by electric currents (although currents and their arcs may be embedded in it) but appears to be due to electrons that leak out of the magnetotail.

Any magnetic trapping is leaky—there always exists a bundle of directions ("loss cone") around the guiding magnetic field lines where particles are not trapped but escape. In the radiation belts of Earth, once particles on such trajectories are gone, new ones only replace them very slowly, leaving such directions nearly "empty". In the magnetotail, however, particle trajectories seem to constantly reshuffle, probably when the particles cross the very weak field near the equator. As a result, the flow of electrons in all directions is nearly the same ("isotropic"), and that assures a steady supply of leaking electrons.

The energization of such electrons comes from magnetotail processes. The leakage of negative electrons does not leave the tail positively charged, because each leaked electron lost to the atmosphere is quickly replaced by a low energy electron drawn upward from the ionosphere. Such replacement of "hot" electrons by "cold" ones is in complete accord with the 2nd law of thermodynamics.

Other types of auroras have been observed from space, e.g.Wikipedia:Citation needed "poleward arcs" stretching sunward across the polar cap, the related "theta aurora", and "dayside arcs" near noon. These are relatively infrequent and poorly understood. There are other interesting effects such as flickering aurora, "black aurora" and subvisual red arcs. In addition to all these, a weak glow (often deep red) has been observed around the two polar cusps, the "funnels" of field lines separating the ones that close on the day side of Earth from lines swept into the tail. The cusps allow a small amount of solar wind to reach the top of the atmosphere, producing an auroral glow.

Sounds associated with auroras

Folktales and travelers' tales say that the aurora can generate noise such as claps, crackles, and static sounds, usually faint and brief. For a long time scientists were dubious, since sound has been hard to document, and auroral displays themselves are too high in the sky for them to be heard on the ground. However, researchers from Aalto University in Finland published a study in 2012 saying that they recorded "clapping" sounds correlated to the visual presence of the aurora borealis, and that these sounds were produced approximately 70 metres (230 ft) above ground. They suggested that these sounds come from the solar particles associated with creating the aurora. The University of Alaska notes that aurora noise is so rare that hearing it is a "once in a lifetime experience", possible only during times of maximum aurora activity, on windless nights away from other noise sources.

Images

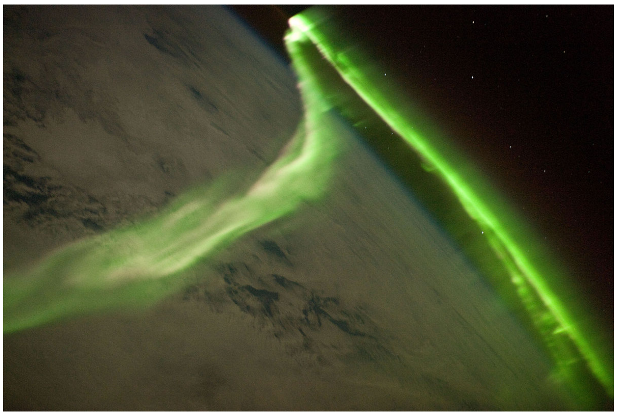
Images of auroras are significantly more common today due to the rise of use of digital cameras that have high enough sensitivities. Film and digital exposure to auroral displays is fraught with difficulties, particularly if faithfulness of reproduction is an objective. Due to the different spectral energy present, and changing dynamically throughout the exposure, the results are somewhat unpredictable. Different layers of the film emulsion respond differently to lower light levels, and choice of film can be very important. Longer exposures aggregate the rapidly changing energy and often blanket the dynamic attribute of a display. Higher sensitivity creates issues with graininess.

25-second exposure of the *aurora australis* from Amundsen-Scott S.P.S.

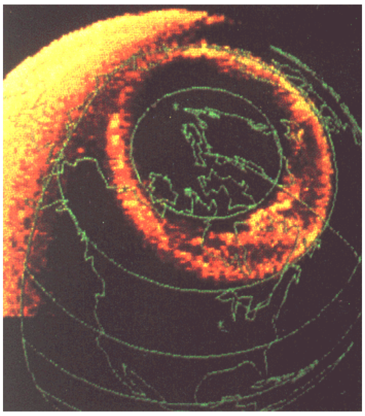
David Malin pioneered multiple exposure using multiple filters for astronomical photography, recombining the images in the laboratory to recreate the visual display more accurately. For scientific research, proxies are often used, such as ultra-violet, and re-colored to simulate the appearance to humans. Predictive techniques are also used, to indicate the extent of the display, a highly useful tool for aurora hunters. Terrestrial features often find their way into aurora images, making them more accessible and more likely to be published by major websites. It is possible to take excellent images with standard film (using ISO ratings between 100 and 400) and a single-lens reflex camera with full aperture, a fast lens (f1.4 50 mm, for example), and exposures between 10 and 30 seconds, depending on the aurora's display strength.[14]

Early work on the imaging of the auroras was done in 1949 by the University of Saskatchewan using the SCR-270 radar.

Red and green auroras, Norway

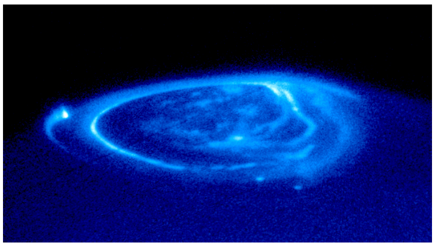


Aurora during a geomagnetic storm that was most likely caused by a coronal mass ejection from the Sun on 24 May 2010. Taken from the ISS



Diffuse aurora observed by DE-1 satellite from low Earth orbit

On other planets

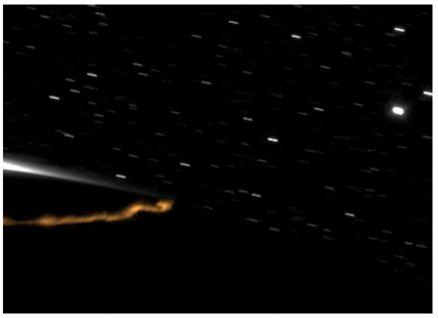


Jupiter aurora; the bright spot at far left is the end of field line to Io; spots at bottom lead to Ganymede and Europa

Both Jupiter and Saturn have magnetic fields much stronger than Earth's (Jupiter's equatorial field strength is 4.3 gauss, compared to 0.3 gauss for Earth), and both have large radiation belts. Auroras have been observed on both, most clearly with the Hubble Space Telescope. Uranus and Neptune have also been observed to have auroras.

The auroras on the gas giants seem, like Earth's, to be powered by the solar wind. In addition, however, Jupiter's moons, especially Io, are powerful sources of auroras on Jupiter. These arise from electric currents along field lines ("field aligned currents"), generated by a dynamo mechanism due to the relative motion between the rotating planet and the moving moon. Io, which has active volcanism and an ionosphere, is a particularly strong source, and its currents also generate radio emissions, studied since 1955. Auroras also have been observed on the surfaces of Io, Europa, and Ganymede, using the Hubble Space Telescope. These auroras have also been observed on

Venus and Mars. Because Venus has no intrinsic (planetary) magnetic field, Venusian auroras appear as bright and diffuse patches of varying shape and intensity, sometimes distributed across the full planetary disc. Venusian auroras are produced by the impact of electrons originating from the solar wind and precipitating in the night-side atmosphere. An aurora was also detected on Mars, on 14 August 2004, by the SPICAM instrument aboard Mars Express. The aurora was located at Terra Cimmeria, in the region of 177° East, 52° South. The total size of the emission region was about 30 km across, and possibly about 8 km high. By analyzing a map of crustal magnetic anomalies compiled with data from Mars Global Surveyor, scientists observed that the region of the emissions corresponded to an area where the strongest magnetic field is localized. This correlation indicates that the origin of the light emission was a flux of electrons moving along the crust magnetic lines and exciting the upper atmosphere of Mars.


An aurora high above the northern part of Saturn; image taken by the Cassini spacecraft, a movie (click on image), shows images from 81 hours of observations of Saturn's aurora

In traditional and popular culture

In *Bulfinch's Mythology* from 1855 by Thomas Bulfinch there is the claim that in Norse mythology:

> The Valkyrior are warlike virgins, mounted upon horses and armed with helmets and spears. /.../ When they ride forth on their errand, their armour sheds a strange flickering light, which flashes up over the northern skies, making what Men call the "aurora borealis", or "Northern Lights".

While a striking notion, there is not a vast body of evidence in the Old Norse literature supporting this assertion. Although auroral activity is common over Scandinavia and Iceland today, it is possible that the Magnetic North Pole was considerably farther away from this region during the centuries before the documentation of Norse mythology, thus explaining the lack of references.


Frederic Edwin Church's 1865 painting "Aurora Borealis"

The first Old Norse account of *norðrljós* is found in the Norwegian chronicle *Konungs Skuggsjá* from AD 1230. The chronicler has heard about this phenomenon from compatriots returning from Greenland, and he gives three possible explanations: that the ocean was surrounded by vast fires, that the sun flares could reach around the world to its night side, or that glaciers could store energy so that they eventually became fluorescent.

In ancient Roman mythology, Aurora is the goddess of the dawn, renewing herself every morning to fly across the sky, announcing the arrival of the sun. The persona of Aurora the goddess has been incorporated in the writings of Shakespeare, Lord Tennyson, and Thoreau.

In the traditions of Aboriginal Australians, the Aurora Australis is commonly associated with fire. For example, the Gunditjmara people of western Victoria called auroras "Puae buae", meaning "ashes", while the Gunai people of eastern Victoria perceived auroras as bushfires in the spirit world. When the Dieri people of South Australia said that an auroral display was "Kootchee", an evil spirit creating a large fire. Similarly, the Ngarrindjeri people of South Australia referred to auroras seen over Kangaroo Island as the campfires of spirits in the 'Land of the Dead'. Aboriginal people in southwest Queensland believed the auroras to be the fires of the "Oola Pikka", ghostly spirits who spoke to the people through auroras. Sacred law forbade anyone except male elders from watching or interpreting the messages of ancestors they believed were transmitted through auroras.

After the Battle of Fredericksburg, the lights could be seen from the battlefield that night. The Confederate Army took it as a sign that God was on their side during the battle as it was very rare that one could see the Lights in Virginia. The painting Aurora Borealis (see *Aurora Borealis* [15]) (1865) by American landscape painter Frederic Edwin Church is widely interpreted to represent the conflict of the American Civil War.[16]

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External links

- Real time solar wind data and aurora forecast (http://www.aurora-service.eu/aurora-forecast/).
- Aurora – FAQ (http://odin.gi.alaska.edu/FAQ/).
- Aurora – Forecasting (http://www.gi.alaska.edu/AuroraForecast/).
- Official MET aurora forecasting in Iceland (http://www.northernlightsiceland.com/northern-lights-forecast/).
- Aurora Borealis –Predicting (http://www.aurorahunter.com/aurora-prediction.php).
- Solar Terrestrial Data (http://www.hamqsl.com/solar1.html#converters) – Online Converter – *Northern Lights* Latitude.
- NASA –Carrington Super Flare (http://science.nasa.gov/headlines/y2008/06may_carringtonflare.htm?).
- Aurora Live Europe (http://www.auroralive.eu) - Aurora forecasts for middle latitudes in Europe.
- Multimedia:
  - Amazing time-lapse video of Aurora Borealis (http://vimeo.com/user10702000/fireinthesky) - Shot in Iceland over the winter of 2013/2014.
  - Popular video of Aurora Borealis (http://nrk.no/nyheter/distrikt/troms_og_finnmark/1.7467857) - Taken in Norway in 2011.
  - Aurora Photo Gallery (http://www.aurora-northern-lights.com) - Views taken 2009–2011.
  - Aurora Photo Gallery (http://fineartamerica.com/featured/red-and-green-frank-olsen.html) - View from Tromsø, Norway. October 2011.
  - Aurora Photo Gallery (http://apod.nasa.gov/apod/ap120103.html) - "Full-Sky Aurora" over Eastern Norway. December 2011.
  - Videos and Photos – Auroras at Night (http://www.twanight.org/newTWAN/gallery.asp?Gallery=Aurora&page=1).
  - Video (04:49) (http://www.youtube.com/watch?v=lT3J6a9p_o8) – Aurora Borealis –How The *Northern Lights* Are Created.
  - Video (47:40) (http://www.nfb.ca/film/northern_lights) – *Northern Lights* –Documentary.
  - Video (5:00) (https://vimeo.com/62602652) - Northern lights video in real time
  - Video (01:42) (http://www.vimeo.com/27315234) – *Northern Lights* – Story of Geomagnetc Storm (Terschelling Island – 6/7 April 2000).
  - Video (01:56) (http://www.youtube.com/watch?v=Lc3FxNXjBs0) (Time-Lapse) -Auroras - Ground-Level View from Finnish Lapland 2011.
  - Video (02:43) (http://www.youtube.com/watch?v=Mb87D5PAMuY) (Time-Lapse) -Auroras - Ground-Level View from Tromsø, Norway. 24 November 2010.
  - Video (00:27) (http://www.youtube.com/watch?v=l6ahFFFQBZY) (Time-Lapse) –Earth and Auroras – Viewed from The International Space Station.

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