

# AN INTRODUCTION TO HF PROPAGATION

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This article is designed to be an introduction to the terms and basic mechanics of propagation methods that are to be found on the HF and VHF bands. The descriptions of the terms quite basic in order to keep them understandable, so they may appear to be a little vague or not technically 100% correct. A complete description would take many pages and require much research, which is beyond the scope of this article. The descriptions given are just an insight into the most important area of our hobby for without the propagation of our signals, there could be no radio communication! If you have an area of interest, I would recommend using the mass of freely available information to further your knowledge of the particular subject. I have arranged the article in a 'Question and Answer' format as this is far easier to digest than a single narrative. Hopefully the range of questions posed and accompanying answers will cover most of the queries raised when trying to understand propagation.

## WHAT IS PROPAGATION?

The term **PROPAGATION** is used to describe how the transmitted signal reaches the receiving station or target area. The way signals reach the receiving station are governed mainly by distance and frequency. That is an over simplification, but this article is designed to be an introduction, rather than an in depth explanation of every mode and variation of propagation phenomena. Other major players affecting MF/HF propagation are the 11 year solar cycle, time of year, day-to-day solar activity and time of day. For VHF (i.e. frequencies above 30MHz) the picture is somewhat different with the weather conditions and the state of the lower atmosphere playing a major role in determining if a station can be contacted. Other things affecting longer distance propagation on VHF are solar activity and location of both transmitting and receiving stations. Best distance under normal conditions can be obtained if there is an unobstructed salt water path between both stations (i.e. between Cornwall and the Canary Islands, which has been achieved on 2m several times).

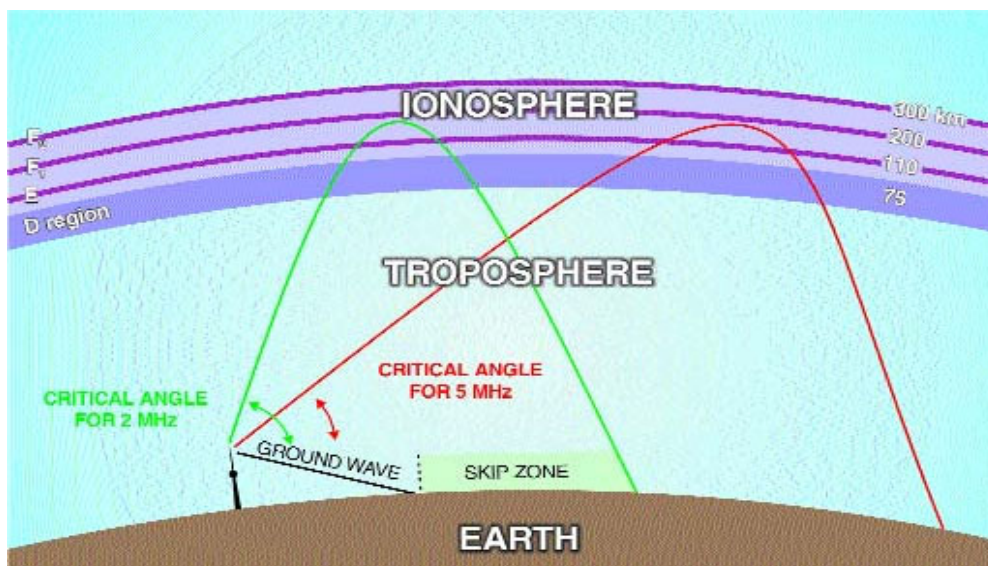
## WHAT ARE THE LAYERS OF THE ATMOSPHERE?

The **ATMOSPHERE**, the envelope of gases that surround the earth is comprised of many different layers, each having an effect on the propagation of radio waves. The atmosphere varies in density, being most dense near the earth's surface and becoming less and less dense as height above the earth increases. Temperature in the atmosphere also varies with height with the rate of change is fairly constant. The portion of the atmosphere where the temperature reduction is fairly constant with height is called the **TROPOSPHERE**. The troposphere extends from the surface of the earth up to a height of 10km or so. This is the part of the atmosphere that contains the right mixture of gases to support life and is also responsible for our weather. The point at which the temperature stabilizes is called the **TROPOPAUSE** and is to be found at around 10-20km above the earth's surface.

From the tropopause to about 60km up we find the **STRATOSPHERE**. This is the part of the atmosphere where aircraft fly as the air is thinner and hence there is less friction and drag, allowing the aircraft to fly faster and use less fuel. Temperature is fairly constant but does tend to actually increase as the top of the stratosphere is reached (the **STRATOPAUSE**). The next layers form the **IONOSPHERE**, perhaps the amateurs greatest asset, perhaps also his worst enemy!

## WHAT IS THE IONOSPHERE?

The **IONOSPHERE** is comprised of several layers of gas located from 70 to 650km (approx) above the earths surface. These layers can combine, split or change their characteristics which makes forecasting conditions a bit of a hit and miss affair. Some properties of the ionosphere are well known and can be predicted with a fair degree of accuracy, whereas others are totally unpredictable. As I said, the ionosphere is split into several layers, each of which has been assigned an identifying letter to, hopefully, ease confusion. Starting at the lowest level, we have the D layer/region, next is the E layer, then the F layers (which are split into F1 and F2). All of these layers/regions have unique properties and each either aids or hinders our efforts to propagate a signal.



### **WHAT IS THE D REGION?**

The **D REGION** is the lowest layer of the ionosphere, extending from about 60km to 100km above the earth's surface. The reason that this area is called a 'region' instead of a 'layer' is that it is only really present during daylight (the time that the sun is illuminating the ionosphere, which is considerably longer than terrestrial daylight). At night the D region virtually disappears allowing signals to pass through to the higher levels of the ionosphere where they will be refracted back to earth (often the term used is reflected, but refracted is the correct description). The D region affects the lower frequencies and is the reason why signals on MW and 160m are confined to a few 10's to maybe a couple of hundred km during daylight hours. While the sun is illuminating the ionosphere, the D region is highly ionised and acts like an RF 'sponge' to MF signals. As the sun sets, the D region becomes less and less ionised and almost disappears, the remaining ionised molecules are spread so thinly as to make little difference to the signal passing through.

### **WHAT IS THE MYSTERIOUS 'E' LAYER?**

The **E LAYER** of the ionosphere is the stuff of radio legends, fantastic feats and has puzzled scientists for as long as they have known about it's existence! Way back in 1902 (just after the 'birth' of radio) 2 physicists, one based either side of the Atlantic, first put forward the idea of there being an ionised layer in the atmosphere. The two were called Arthur Kennelly (USA) and Oliver Heaviside (UK), hence the old term for the E layer, the "Kennelly-Heaviside Layer". Edward Appleton carried out experiments during 1924 to confirm not only the existence of the Kennelly-Heaviside layer, but that in fact there was at least one other layer above it. Appleton was the first person to refer to the Kennelly-Heaviside layer by it's now common name, the E-layer. He named it the E layer because, he considered, it reflected the "electric" field of the radio wave. The layer above this he named the F-layer. The F-layer is sometimes still referred to as the "Appleton Layer". Subsequently another layer, below the E layer, was discovered by Robert Watson-Wyatt, and designated the D layer (or region, for the reasons described previously). The E layer is located around 100-130km above the earth's surface and the air density is still quite high, allowing the recombination of molecules (ionisation) to take place easily. As the sun illuminating the ionosphere causes ionisation, the ionosphere is most ionised at local midday. After sunset, ionisation rapidly falls off until it has all but ceased.

### **WHAT ARE THE 'F' LAYERS?**

As Appleton had discovered, there is another layer above the E layer which he named the F-layer. What he didn't realise is that the story is not quite that simple and the F-layer is in fact comprised of 2 layers that recombine at night (so can one assume he did his experiments at night?). To differentiate these layers, they were identified as F<sub>1</sub> and F<sub>2</sub>. The F<sub>1</sub> is the lower of the two and is to be found at heights of 150-250km. The higher F<sub>2</sub> layer extends from about 300-500km or so. As stated, these heights are only valid during daylight. At night, the layers combine and form a single layer at a height of about 250-350km. These heights vary according to time of year, the solar cycle and latitude. Because the F layers are the only ones that are present in some form 24 hours a day, they are considered to be the most important part of the ionosphere as far as radio communications are concerned.

### **WHAT DOES THE TERM "CRITICAL FREQUENCY" MEAN?**

The **CRITICAL FREQUENCY** is the highest frequency that will be returned to earth when the wave is radiated vertically (this is very different to being **VERTICALLY POLARISED**) towards the ionosphere. Once the critical frequency is passed, the radio wave will not be returned to earth and will travel out into space. When listening to propagation forecasts, the term "**F<sub>2</sub> DAYTIME CRITICAL FREQUENCY**" will be heard. What this means is that the frequency stated is the highest frequency that the F<sub>2</sub> layer will return to earth during daylight (as the F<sub>2</sub> layer ceases to exist during darkness). When written, the symbol for critical frequency is '**f<sub>0</sub>**'. Sometimes the critical frequency is measured against the E layer instead of the usual F layer. The symbol used to denote an E layer critical frequency is '**f<sub>0E</sub>**'. The f<sub>0E</sub> is usually around 2-4MHz, depending on time of day, year and solar cycle.

### **WHAT DOES THE ABBREVIATION "MUF" STAND FOR?**

The term "**MUF**" is used a lot in radio communications and stands for "**MAXIMUM USABLE FREQUENCY**". As we have just seen, when a radio wave is transmitted vertically, it will not be reflected back to earth above a certain frequency. If the angle of the radiated wave is changed from vertical to something nearer horizontal, the frequency at which it will be reflected increases significantly. To calculate roughly the MUF, multiply the F<sub>2</sub> critical frequency by 2.15. The MUF, however, varies considerably dependent on the location of the transmitting station and the path attempted. The path with the highest MUF from the UK tends to be towards South America, which is why South Americans are often the last stations to fade out on the HF bands before they close for the night. It is an extremely useful thing to know the MUF of a given path as the maximum chance of working a station is obtained from using the band that is closest in frequency to the MUF (check beacons in the part of the world you are interested in to see the highest band they can be

received on). A strange thing is that you may be able to hear loud signals from the desired location but cannot make contact. If this happens (and it will!), try switching to the next band up. Signals may be much weaker, but you will be surprised that more often than not you will be able to make the contact without problem. As signals are weaker, this is a sure sign that you are near the edge of the MUF and exploiting this fact will provide many more contacts with far off places than using the lower band, despite the stronger signal levels on the lower band. This is using the MUF to your advantage. If you are interested in working DX, it is advisable to obtain one of the excellent propagation prediction programs that available. Most are freeware or shareware and provide good results. A word of warning though, don't take the results from these programs as gospel, as day to day variations can throw a spanner in the works. If you need to input solar data (as some require), try to obtain monthly average figures as they will give a much more accurate result. Making best use of the MUF can give surprising results and if you are restricted to low power (say 10w, as the foundation licensees are) or poor antennas, this is often the only way to compete with the big guns. Using this, and other, aids is how I have managed to work over 160 countries using just 3 watts and simple antennas. Operating skill plays a part, but using the available resources such as knowing the MUF and how the bands react during the course of the day, month, year etc. will be even more valuable.

### **WHAT IS THE ANGLE OF RADIATION AND WHY IS IT IMPORTANT?**

As discussed earlier, if a radio wave leaves the transmitter at an angle less than vertical, it will be reflected back to earth at a higher frequency. Also it will be reflected back at a distance from the transmitter. This is obviously a vital fact if we are wanting to contact someone who is some distance from the transmitting site. At high angles of radiation, signals will be reflected back down at a short distance from the transmitter. As this angle is decreased towards the horizontal, so the distance covered by the reflected wave increases. The angle at which the radio wave leaves the transmitting antenna is known as the '**ANGLE OF RADIATION**'. As the radiation angle is reduced, so the distance covered by each reflection increases, hence the need for an antenna with a low radiation angle when trying to work long distances on the HF bands. The angle that the transmitted wave hits the ionosphere is known as the '**ANGLE OF INCIDENCE**', and can be different to the angle of radiation (due to anomalies in the atmosphere before it reaches the ionosphere). If you are interested in working long distances, then you would equip your station with a low angle antenna (such as a well grounded vertical or a high multi element beam type antenna). If, however, your interests lie in shorter distances (for example, UK nets on 80m), then a low dipole would be a better option as it will have a much higher radiation angle than a beam, vertical or high dipole. I am talking of heights with respect to wavelength rather than physical height in metres. A low dipole on 80 would be anything less than about 60 feet, whereas a yagi for 10m would be considered to be high if it were located at the same height. If you are looking to work long distances on 80m (and 40m for that matter), very few people are able to erect a dipole at sufficient height (120 feet would be a minimum to negate effects from the ground), so a vertical is a much better alternative. It should be borne in mind that in order for a vertical to have a low angle of radiation an extensive radial system needs to be employed.

### **WHAT ARE N.V.I.S., GROUNDWAVE AND SKYWAVE?**

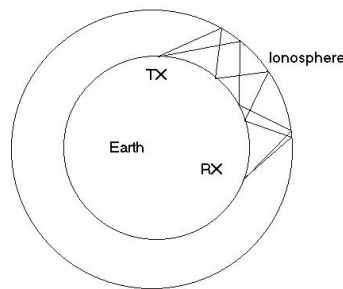
N.V.I.S. is the acronym for Near Vertical Incidence Skywave (or 'cloudwarming' as it has become known amongst us radio folk). NVIS is the art of sending a nearly vertical radio wave up into the ionosphere, so that it may be reflected back at a short distance from the transmitter. It is particularly useful at low frequencies to cover the "**SKIP ZONE**", the area that that is longer than the distance covered by **GROUNDWAVE**, but shorter than the first normal reflection (or hop) from the ionosphere. The groundwave is the part of the signal that travels along the surface of the earth to the receiver. The strength of the groundwave is inversely proportional to frequency, being strongest at low frequencies. As frequency is increased, the distance covered by the groundwave decreases. Local MW stations rely on the properties of groundwave propagation to reach the target audience. As the range of a MW groundwave signal is limited to a 100 or so km during daylight, stations that are geographically separated by 200km or so can operate on the same frequency without causing interference to each other (in theory!). The **SKYWAVE** is the part of the signal that is sent skywards and is reflected from the troposphere with the **SPACEWAVE** (not a term in common use these days) being the part that is reflected from the ionosphere. The Skywave is now taken to mean any signal other than the groundwave. As the D layer disappears at night, MW signals from the continent and further afield can be heard as they are being propagated by skywave. Normally skywave signals on MW would not be heard during daylight as the D region would absorb the signals like an RF sponge. stations that are within the skip zone cannot be heard as there is no method of getting the signal to the receiver. NVIS is a relatively new technique to try and get signals into the skip zone. By sending a nearly vertical wave to the ionosphere and near, but not above, the critical frequency, it should be possible to get a signal to reflect into the skip zone.

### **WHAT IS MEANT BY 'MULTI HOP'**

As we have seen, signals can be reflected off the ionosphere back to earth at a distance governed by the angles of radiation and incidence and by the frequency in use. The maximum distance that be covered in a

single 'hop' as it is known is about 4500km. So how can we hear signals from 15000km? The answer lies in the ionosphere (as usual), each time a signal is reflected back to earth, some of the signal is bounced back to the ionosphere. The type of terrain the signal meets when it reaches earth determines how much will be reflected back to the ionosphere. Salt water is one of the best reflectors as far as this is concerned, so a signal that hits salt water (i.e. the sea or ocean) will suffer much less attenuation than a signal that bouncing from a dry desert. Each time a signal bounces it loses some of it's strength and eventually can become so weak that it is no longer detectable. When the signal enters the ionosphere it also suffers attenuation due to the friction (and hence heat) of the radio wave vibrating ionised molecules. Other strange effects can take place in the ionosphere and the signal may travel a considerable distance within the ionosphere itself before returning to earth, so predicting where a radio wave will return is a bit hit and miss! The term '**MULTIHOP**' describes the action of a radio wave bouncing back into the ionosphere and subsequently being returned to earth more than once. To traverse the distance between here and Australia would take 4-5 hops, or more if the signal was being propagated the other way '**LONG PATH**'. The diagram below illustrates multihop propagation. You can see that it is possible to contact a station by using a higher angle of radiation and taking more hops, but this means the signal will be weaker than the lower angle choice that uses less hops (the fewer the hops, the less the signal is attenuated). Another way signals can be propagated is via '**CHORDAL HOP**', which is where the signal bounces from the upper ionosphere without sufficient strength to return to earth. The signal becomes 'trapped' between the lower and upper levels of the ionosphere and bounces, or hops, within the ionosphere. Eventually, the signal strikes the upper layers at an angle sufficient to allow it penetrate the lower levels of the ionosphere and return to earth. The advantage of chordal hopping is that the signal suffers much less attenuation than if it were to return to earth each time before bouncing to the higher ionospheric levels.

Diagram showing two possible paths, one with two hops and one with three hops



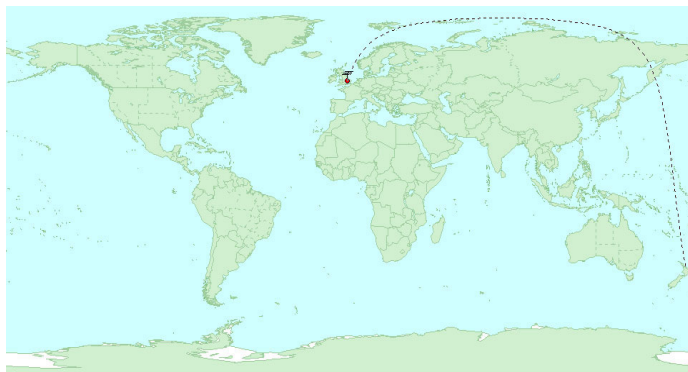
### WHAT IS 'SHORT PATH' AND 'LONG PATH'?

When a radio wave is propagated to a distant place, it travels in a theoretically straight line (the shortest distance between two points is a straight line). Now with the earth being a sphere, normal maps (with the



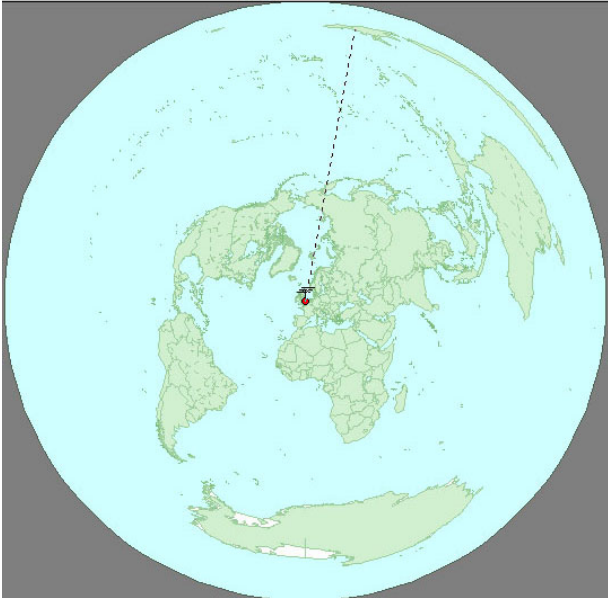
Mercator projection) will give you false information as to how the radio wave reaches it's target. To get the true picture you need to look at a globe or a special type of map called a '**GREAT CIRCLE**', which is a representation of the globe if it were flattened onto a piece of paper.

This picture shows how you would expect a radio wave to travel from England to New Zealand, as viewed on a Mercator projection map.

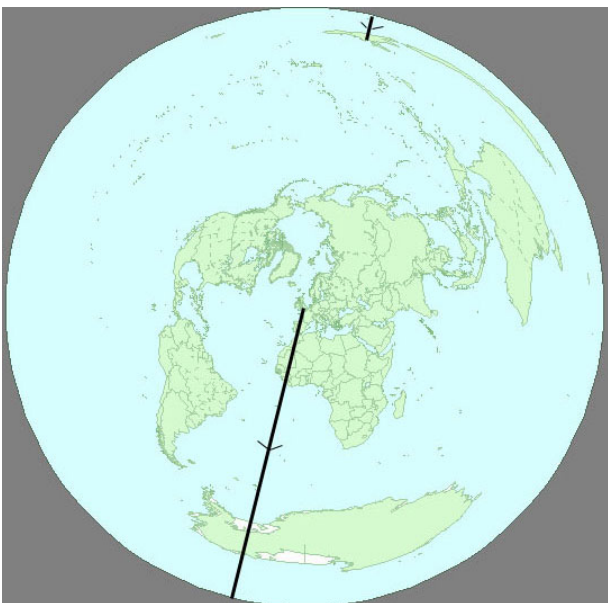


The actual path taken by the England to New Zealand signal viewed on the same map.





The England – New Zealand path as shown on a great circle map (notice that it is a straight line and crosses over the North Pole). If an aircraft were to fly direct from the UK to New Zealand, this would be the preferred route as it is the shortest or **SHORT PATH**. Most radio communication on the HF bands is conducted via Short Path.



This is the **LONG PATH** from UK to New Zealand, which is the exact opposite of the most direct route. The signals are propagated to the desired location by beaming your signals 180 degrees from the normal heading. The signals can be stronger at certain times of the day when propagated via long path. Sometimes long path is the only path that has an MUF high enough to support communication to the desired location. When using an omni directional antenna, such as a vertical or low dipole, signals can be received from both short and long path simultaneously, which can lead to confusion at the receiver as there will be a noticeable echo on the signal (the long path signal has travelled considerably further so takes longer to reach the receiver). This echo is only a few 10's of milliseconds but can play havoc with CW reception as the spaces between characters can be filled in with characters from the echo signal rendering the signal almost unreadable. The echo length varies in proportion to the distance travelled. Listening to a New

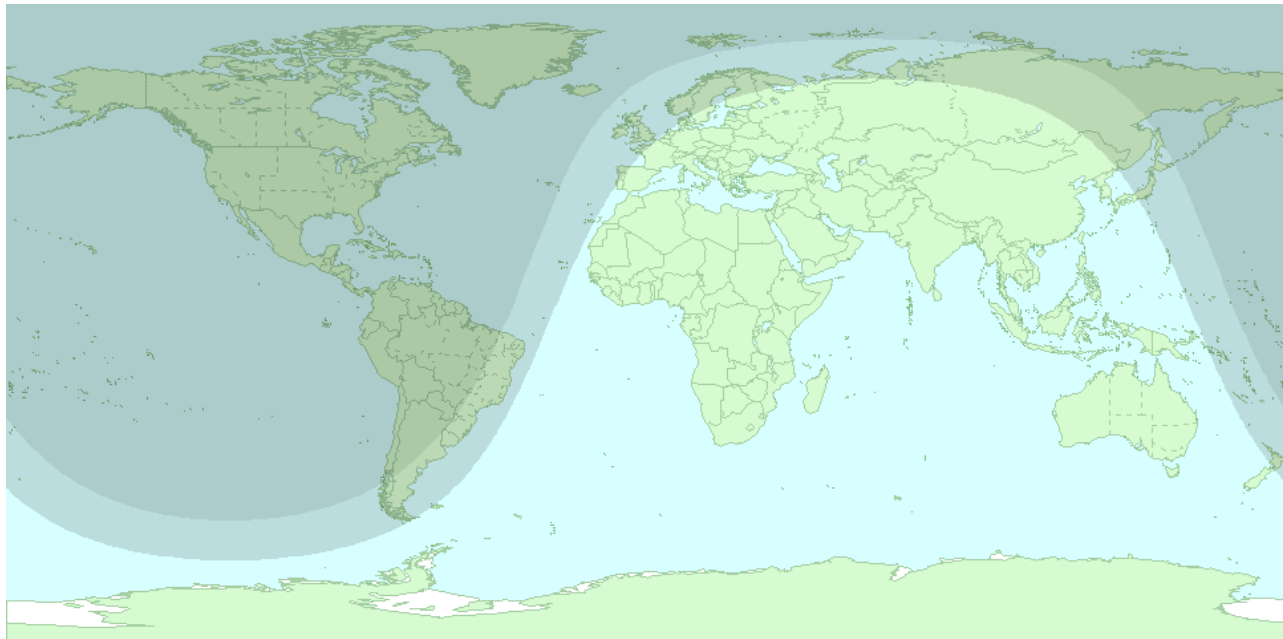
Zealand station on both paths would not cause to many problems as the difference in path length is minimal but listening to a West Coast USA station via long and short path simultaneously causes real headaches as there is a considerable difference in path lengths which produces a delayed echo. Weak CW from California in the late afternoon on 14MHz with a vertical can be almost impossible as both long and short path signal strengths are almost identical, rendering the signal into a garbled mass of dots and dashes. A directional antenna, with the ability to rotate would make life a lot easier!!

### WHAT IS THE 'GREYLINE'?

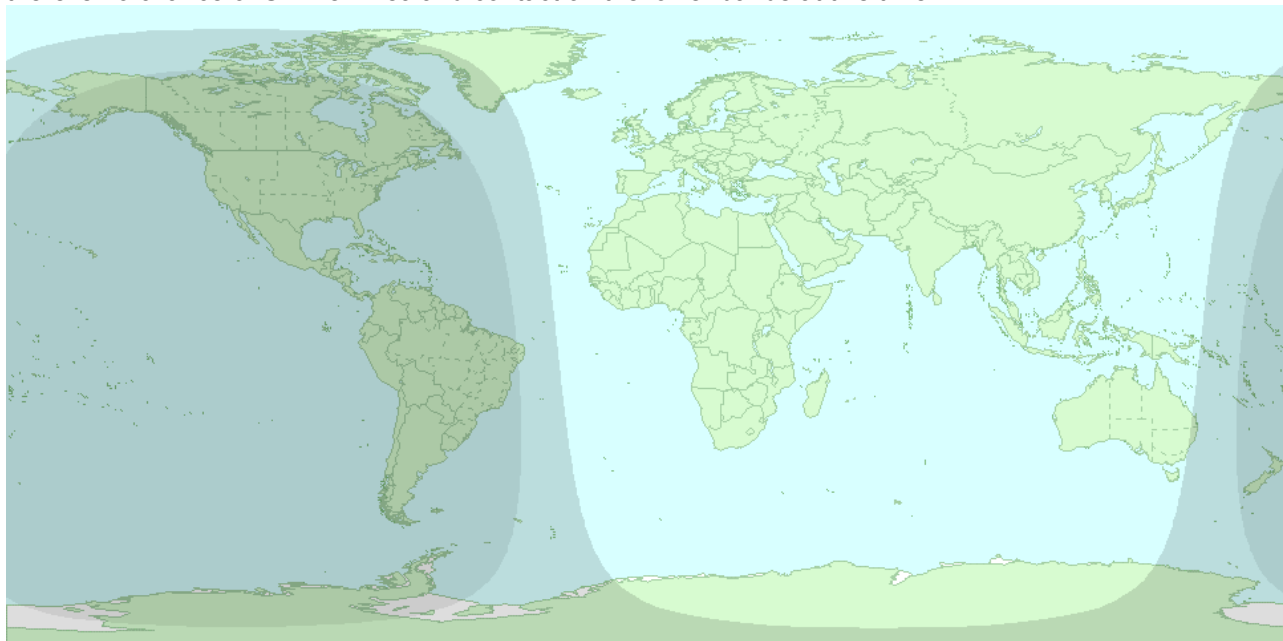
The **GREYLINE** terminator is the imaginary line drawn on a map to show daylight and darkness. The greyline is very important for radio communications and is another thing in our weaponry that we can use to get our signal to the desired location. As darkness falls, we enter the twilight zone, where it is not really light, but it isn't completely dark either. When the stations at both ends of the path are near darkness, signal levels often increase for the period that both stations are in twilight. Often this is the **ONLY** time contact can be made between stations on a given band. Typically this affects lower bands more (160-40m) but there is increasing evidence that using the greyline can be advantageous on all HF bands. This 'window of opportunity' only exists for a short time, especially on the lowest frequencies before absorption increases to such a level that the signal cannot penetrate the D layer (which is now building in strength as the path comes into daylight). On 160m (1.8MHz), the window can be as little as 20 mins or even less between UK and New Zealand. If you are looking to work the other side of the world on 160m, you need to be prepared as a few minutes either way can mean the path being closed. Greyline paths are not open every day, as you need suitable propagation conditions to the intended target. The best times to try this path is around the equinoxes (March and September) and at dawn or dusk.

The illustrations below show daylight, darkness and the GREYLINE, which is the lighter grey area.

The GREYLINE of December 7<sup>th</sup> at 1940 UTC. Communication between UK and the Northern part of New Zealand's North Island on top band or 80m may be just possible at this time if other propagation factors are favourable.



The GREYLINE as seen on September 7<sup>th</sup>, 1940 UTC. As you can see the UK is in complete daylight so there is no chance of UK-New Zealand contact on the lower bands at this time.



I have found the best (and only time so far!) for me to contact New Zealand on 80m (3.5MHz) is at the end of March at around 0600z. I have completed this path 3 successive years during the solar maximum.. One reason I can give for this is that most of Europe will be in daylight by 0600, so the attenuation caused by the rapidly forming D-layer absorbs signals to them from New Zealand, and also from them to the target. The UK is still in twilight and has much lower absorption. The signals should be getting stronger as we head down to the bottom of the 11 year cycle but it's still not an easy task to get your signal through although it is possible with a little luck and a lot of perseverance.

## WHAT IS THE S.F.I.?

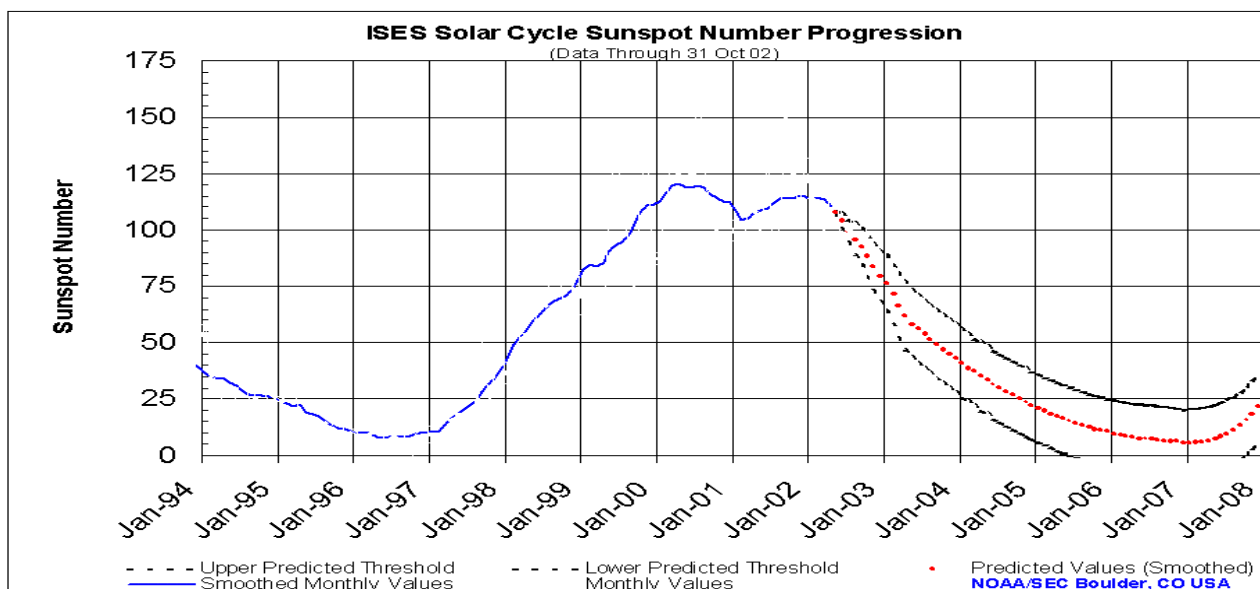
**SFI** stands for **SOLAR FLUX INDEX**. The SFI is a figure derived from the number of active sunspots visible on the face of the sun based on observations of thermal and radio noise received at a wavelength of 10.7cm. (2.8GHz) at an observatory in British Columbia, Canada. The thermal noise is related directly to the amount of plasma trapped in the magnetic field that overlies the active regions of the sun, which in turn is related to the amount of magnetic flux (the lines of force generated by a magnet) generated by these active regions.

## WHAT ARE SUNSPOTS?

A **SUNSPOT** is an area of intense magnetic activity on the surface of the sun which is cooler than the rest of the sun's surface. Because it is cooler, a sunspot is darker and therefore visible against the hotter, brighter background. Some sunspot clusters are so large they can be seen without magnification. The next sentence is extremely important and **must be adhered to at all times** when observing the sun. **NEVER LOOK DIRECTLY AT THE SUN, ALWAYS PROJECT THE SOLAR IMAGE ONTO A PIECE OF CARD WHEN MAKING OBSERVATIONS. FAILURE TO DO THIS CAN RESULT IN PERMANENT BLINDNESS.** There are filters on the market that supposedly make it safe to look at the sun directly - don't trust them! If you value your eyesight, you will never look at the sun directly. Another advantage of projecting the sun onto a card is that the image can be magnified, making the identification of sunspots easy. Sunspots are a vital part of long distance radio communications as they are tied to the ionisation level of the F layer. The more active sunspot groups, the higher the magnetic and ultraviolet radiation from the sun and the higher the SFI. If a graph were plotted of daily sunspot numbers, it would be rather spiky and difficult to interpret over time, so a method of averaging is used, called 'smoothing', which gives us the **SMOOTHED SUNSPOT NUMBER** or **SSN**. In the years where there are few or no sunspots, radio propagation on the higher bands can be non-existent. However all is not lost as the lower frequency bands tend to improve as solar activity declines.

## WHAT IS THE SOLAR CYCLE?

Every 11 years or so the sun goes through a complete cycle of events. At the beginning of a new cycle, the first sunspots are noticed on the otherwise blank solar disc. This first batch of sunspots heralds the gradual improvement in the higher HF bands. At the very bottom of the cycle, where few or no sunspots are visible, the bands from 21MHz up can be dead for weeks on end. Except for some localised ionisation during the summer which supports inter-Europe contacts, virtually no signals will be heard. Trying to work long distances during sunspot minima on 15 or 10m is a thankless task! Over the next 4 or 5 years, more and more sunspot groups become active. As more groups are active, so geomagnetic levels in the sun rise and the ionosphere becomes increasingly ionised, leading to an increase in the MUF and hence better conditions on the higher bands. The years 2000-2001 saw the peak of the current 11 year solar activity cycle where many groups were active, and remained active for long periods. This solar cycle was predicted to be the best for many years, but those who have been active for a few cycles will know that it did not live up to expectations! An unusual feature of this cycle was that it appeared to have two peaks. The first occurred in the middle of 2000, with a tail off around the beginning of 2001. The second peak was around late 2001, with conditions beginning to trail off during 2002. We can expect conditions on the higher bands to fall off over the next 3 or 4 years with the minima in 2007-2008. This '11 year' cycle is an average and can be anywhere from 9 up to about 15 years between maxima. The term solar activity refers to a combination of the amount of sunspots and also the effect the solar geomagnetic activity has on the earth's magnetic field. At sunspot maxima, solar activity is generally high (or active) due to the increase in sunspot activity and at sunspot minima, solar activity tends to be at low (or quiet) levels.



The diagram shows the progression of the current solar cycle, with the prediction for the next minima being around June 2007. The “double hump”, or twin peak can be clearly seen. Expect conditions to deteriorate steadily over the next few years.

### WHAT ARE THE A AND K INDEX?

The explanation of the solar cycle is based on ‘smoothed’ figures, that is the average figures for each month are used rather than using daily figures. The reason for this is to give a more accurate picture than using daily figures would. Day to day solar activity can vary dramatically, so using these figures for propagation prediction can lead to unsatisfactory results. As well as variations in the geomagnetic flux, there are two other measurements of the magnetic field activity (caused by interactions of the solar wind the magnetosphere and the ionosphere) that are used in predictions. These are the **A AND K INDICES**. The K index is a 3 hourly reading of the magnetic activity compared to a standard ‘quiet’ day taken at various observatories. This index was first introduced by J. Bartels back in 1938 and consists of a single number in the range 0-9. The planetary K index (Kp) is the mean or average index of readings from 13 observatories located between 44 and 60 degrees latitude each side of the equator. The planetary index measures solar particle radiation by it’s magnetic effects. The A index relates to geomagnetic stability and is derived from the K indices of the previous day. The Planetary A index (Ap), is derived from the A indices of the world wide network of magnetometers.

The relationship between A and K index is shown below:

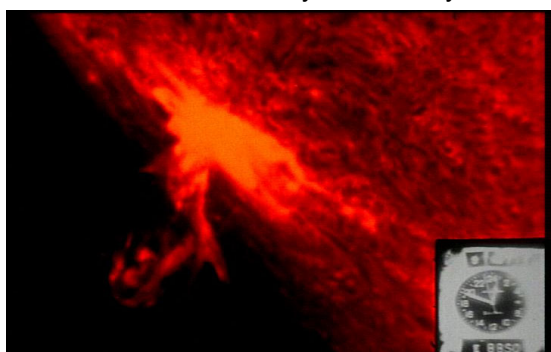
K	0	1	2	3	4	5	6	7	8	9
A	0	4	7	15	27	48	80	132	207	400

When looking at the A or K figures, the lower the better as far as propagation conditions go! For best conditions look for A and K indices of 0 which have been sustained for a few days, coupled to a high SFI (above 250). You can then expect excellent propagation on the HF bands (unless one of the short lived solar events described below occurs at the same time then, of course, that theory doesn’t work!). K indices of 3 or below are considered to be ‘quiet’, whereas a k index of 9 indicates severe geomagnetic storm level. For the Lower bands (1.8, 3.5 and 7MHz), sustained very low A and K indices coupled with a low SFI are the best conditions for long distance working (especially if the required path crosses either of the poles).

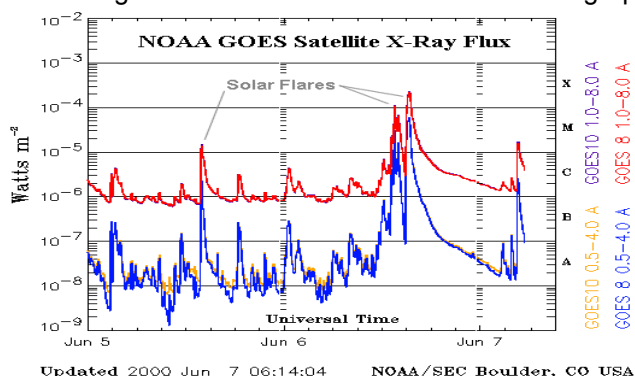
### WHAT IS A SOLAR FLARE/GEOMAGNETIC STORM?

As mentioned above, the A and K indices give us a good indicator to propagation conditions. As the index increases so geomagnetic activity increases until a level is reached that has been classified as storm level. A solar storm occurs when nuclear fission within the sun reaches such a high level that matter is ejected outwards from the sun, towards the earth. The most common of these is the **SOLAR FLARE**, many of which occur during the course of a year. These flares range in intensity from mild to severe. The strength of a solar flare (X-ray flux) is measured by the GOES spacecraft and is denoted by a letter and number system. The strength ranges from the weakest, A, through B, C and M to the most severe, X. Within these classes, a further subdivision using a numeric system is made ranging up to 9, so the most severe flare would be classed as an X9 event. Thankfully there are few of these during an 11 year cycle. A flare is considered significant if it rises above M levels. To put a solar flare into context, large flares can emit 10 million times the energy that is released by a volcanic eruption. Such an intense release of energy not only disrupts earthly communications but it can also cause damage to satellite control systems as they do not have the benefit of an atmosphere do dampen the force of the shock wave. A solar flare travels at such speed that within 10 minutes or so of eruption it can reach the earth’s atmosphere causing short-lived radio blackouts on the sunlit side of the earth.

A prominent solar flare on the South East of the solar disc, as seen by a soft X-ray telescope .



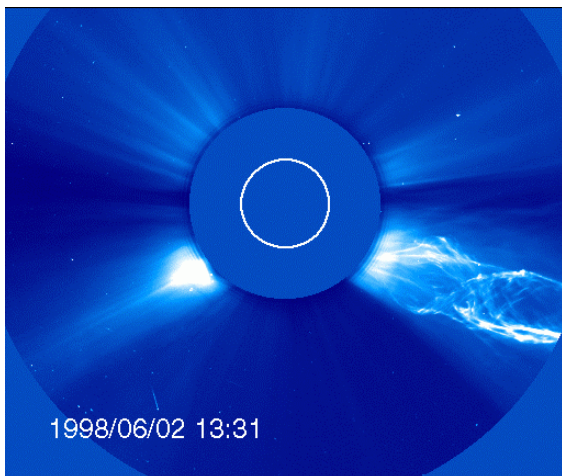
Strong X-class solar flares are visible on this graph





### WHAT IS A CME?

Another common result of excess nuclear activity within the sun is the **CME** or **CORONAL MASS EJECTION**. A CME is an explosion within the sun that causes large amounts of solar matter to be ejected into space. This ejection causes a 'shock wave' of magnetic disturbance to head towards earth. When the shock wave hits the ionosphere it disturbs the earth's magnetic field to such an extent that some of the electrons in the field can be lost to the shockwave. This disturbance to the magnetic field shows up as a rapid increase in the A and K indices. With electrons missing, the ionosphere loses ionisation, the MUF falls and absorption can increase to such a level that virtually all HF communications are wiped out. Once the CME has passed, it can be several hours or even days before the earth's magnetic field returns to normal and the missing electrons are replaced, allowing higher levels of ionisation to once again occur. A CME travels much slower than a flare and can take a couple of days to reach a distance that will cause disruption to communications.



A spectacular CME, showing just how much matter is ejected into space, and ultimately towards the earth and our ionosphere.

### WHAT IS AN S.I.D.?

An **S.I.D.** is the abbreviation for **SUDDEN IONOSPHERIC DISTURBANCE** and occurs as the result of the disturbance to the earth's magnetic field caused by a large solar flare. As the name implies, these events happen suddenly, sometimes within 10 minutes of a large eruption from the sun. An SID only affects the part of the earth that is illuminated (due to the increase in absorption caused by the D region, which disappears after dark) and is often short lived. The effect on HF communication can be drastic, with signals from everywhere fading from being solid copy to literally disappearing within seconds. The effect is quite spectacular and a little eerie if you have not experienced an SID before. Sometimes SID's are known as **RADIO BLACKOUTS** or **DELLINGER FADEOUTS**. You can expect radio conditions to return to normal, or near normal within an hour or so, except in large events where the disruption can last for several hours.

### WHAT IS PCA?

**PCA** or **POLAR CAP ABSORPTION** happens as a result of large X class flares, which contain high energy protons (in the order of 10MeV) that are attracted towards the magnetic fields around the polar cap regions of the earth (also known as a solar proton event). The resulting disturbance to the earth's magnetic field around the polar regions leads to an increase in absorption (caused by the D and E layers increasing in density), making communications paths that cross near or over the poles almost impossible. Signals that pass the poles tend to gain a noticeable 'flutter' as the magnetic field density is different, and the level of absorption varies rapidly, this phenomena is known as **POLAR FLUTTER** and has a sound that is distinctive enough to easily identify a signal propagated by this mode. Because a PCA event affects both the D and E layers, the disturbance to communications can last for days.

### WHAT IS AURORA?

**AURORA** is a phenomena associated with high levels of solar activity. Visibly, aurora is known as the Northern Lights (in the Northern Hemisphere) or, to give it the proper name, Aurora Borealis. In the Southern Hemisphere, the phenomena is known as the Southern Lights or Aurora Australis. Seeing the Northern lights is an awe inspiring sight and can be spectacular during intense events. In radio terms, an auroral event causes excitement amongst VHF operators who can make contact with stations that are at distances well beyond their normal capability. A visible aurora requires much less energy than a 'radio' aurora. If an aurora is visible, it doesn't necessarily follow that there will be a radio event. Although it needs to be dark to see an aurora, they can occur at any time of the day and most radio auroras start in the afternoon, last for an hour or two before fading out and then return for a second period around midnight. Some stronger ones have a 3<sup>rd</sup> period of activity the following morning. If you notice a radio aurora, make a note of the date and check back



27 days later - you will probably find another one in progress! This is due to the sun making a complete rotation in 27 days, so the part of the sun that was causing the aurora will be in the same position 27 days after the first aurora was noticed. If the event was particularly intense, a check after another 27 days may well see another, weaker, event. Aurora is caused by intense ionisation in the upper atmosphere due to the ionosphere being bombarded with electrically charged particles. When a large solar flare occurs, huge amounts of plasma and other material are thrown towards the earth. When this material enters the ionosphere, the friction developed by the material moving through the various gases causes a heating effect, which in turn causes light of varying wavelengths. This light is the Aurora Borealis! Different gases give off different colours when they are excited by the bombardment of extra-terrestrial materials. Oxygen at about 60 miles up gives off the familiar green and green/yellow colour, Oxygen at higher altitudes (about 200 miles above us) gives the all red auroras. Ionic Nitrogen produces the blue light and neutral Nitrogen gives off a red-purple glow and is responsible for the rippled edges. The picture shows a pair of green tails taken during an intense display in Michigan, USA. From the

picture we can assume that this was a low altitude aurora where Oxygen was the main gas being disturbed. Auroral events are confined to higher latitudes, normally around the polar regions. Stronger, more intense events can be seen from lower latitudes. In the Southern UK auroral displays are somewhat of a rarity but certainly not unheard of. There was an impressive display visible from Buckinghamshire recently (as shown on the cover of "RADCOM"!)). Those who live above the Arctic circle see many auroral displays during the course of a year, but suffer poor HF propagation on more days than us folk who live further South. The effects of Aurora from a communications point of view are only really noticeable on the VHF bands (although the higher HF bands show the characteristic rasp of a signal that has been propagated by Aurora). There are many articles written about working aurora, so I will not go into them here. Signals that are propagated by aurora for some reason tend to lose all tonal quality and sound 'ghostlike' and raspy. SSB signals are very difficult to read as they sound like raspy, ghostlike whispers. CW is a much better alternative, although the normal tone of about 700-1000Hz is replaced by a hissing click.

#### WHAT IS SPORADIC E?

**SPORADIC E** Although **Sporadic E** (abbreviated to **SpE** or **Es**) is normally associated with VHF, it also affects the higher HF bands with effects being noticeable from about 21MHz. Sporadic E is the term used to describe extremely intense ionisation of the E layer of the ionosphere. As the name suggests, sporadic E does not follow a set of rules and occurs without warning. There is a sporadic E 'season', where the chances of an occurrence are more likely. This season lasts from May to September, with a shorter season sometimes occurring around the end of the year. Sporadic E is very localised, so much so that a station on one side of a town may be experiencing an opening, while a station located on the other side of the town can hear nothing. Sporadic E moves around in highly ionised 'clouds', so it pays to be patient, especially if someone near you is working Es as your turn may well come soon. Signals propagated by Es tend to be very strong and in the range of 1000-2500km. Rarely, double hop Es occurs where the signal bounces down from the sporadic E cloud and returns to find a second cloud before finally resting at the receiver, so the signal can be propagated upto about 5000km. Sporadic E affects the higher HF and lower VHF bands. Sporadic E has been recorded upto about 250MHz, but this is extremely rare. In the UK, for every Es season, only 3 or 4 days will see ionisation strong enough to provide contacts on 144MHz. At 50MHz, Es can be heard most days of the season. A typical Es event on 50MHz would last from a few minutes to a few hours, depending on the intensity of the cloud. Sometimes in the summer months, the FM broadcast band from 88-108MHz can become swamped with stations from Europe. These stations can be strong enough to wipe out local FM signals. A few years back, I was at work one afternoon listening to Radio 1 on FM when, with no warning, Radio 1 was replaced with an Italian broadcast station. Upon checking the rest of the FM band, virtually all I could hear was Italian and Spanish stations. This was intense sporadic E, and I was trapped at work! Most Es events seem to occur during daylight, but it may just be that no-one is monitoring in the middle of the night! The origin of sporadic E is still not fully understood and there are numerous theories in circulation. One theory that seems to work is that sporadic E will occur near to an area that has recently experienced a violent electrical thunderstorm. My guess would be that the lightning produces ionisation of the lower atmosphere, some of which finds its way up into the E layer. If you intend to work Es, the cloud will need to be between you and your intended target (to act as a mirror for your RF), so look for thunderstorms over France or Germany. Sporadic E is sometimes known as '**SHORT SKIP**', because the hop distance is less than normally associated with ionospheric propagation. If you are working Es on 50MHz and notice that the distance you are contacting seems to be getting shorter and shorter, this is a sure sign that 70MHz or even 144MHz may well be opening soon. This would be a good time to start monitoring the FM broadcast band for signs of European's. To give you an idea of what can be achieved, just a few watts (10w is plenty) and a dipole will get you all over Europe on 50MHz without problem. I have worked Malta on 144MHz SSB

using just an FT290 at 2 ½ watts into an HB9CV 2 element beam, thanks to the wonder of Sporadic E! On 28MHz, Sporadic E is responsible for the very strong European signals that fill the band during the summer months. Normally Sporadic E is 'SINGLE HOP', that is a single E layer reflection. However, during years of high solar activity, 'DOUBLE' or 'MULTI HOP' Es occur where the signal is reflected back into the E layer and finds another highly ionised patch and is reflected back to earth once again but at a much greater distance than for a single hop. Double Hop Es is a very common method of propagation at 28MHz and is also responsible for quite a few of the transatlantic openings on 50MHz (most of the others being by F2 reflections). Sporadic F and Sporadic D can also occur, affecting the F and D layers respectively, but this is not a very well documented phenomena.

#### **WHAT IS BACKSCATTER?**

**BACKSCATTER** is a mode of propagation that allows you to hear a signal that would be inaudible when propagated via 'normal' methods. The scatter signal comes from a signal that is propagated along a path that would make the signal fall within your skip zone (i.e. the area that is beyond ground wave and not far enough away to allow reception of the first ionospheric bounce), the signal is then 'scattered' to an area that IS audible to you. Signals propagated by this mode tend to be weak and 'hollow' sounding with some distortion. Typical distances covered by scatter are in the order of 1-200 miles at HF, so the Northern part of England, Belgium and the Netherlands are all likely to be heard by backscatter. If you tune the HF bands and hear a weak, hollow signal from a fairly local station then you will be hearing them by backscatter. It is difficult to know whether you will be able to make contact as they may not be hearing YOU via backscatter.

#### **WHEN WILL THE BANDS OPEN TO THE DESIRED TARGET AREA?**

The answer to this question is quite involved as there are many variables to be considered but a few well known properties of each band can give us at least a rough guide as to what countries may be heard at a particular time of day. This is only a guide and is dependant on such things as time of year, solar activity and the capability of your own station. It would be unreasonable to expect a station running low power and indoor antennas to hear and work the same amount of stations as a high power station with large outdoor antennas. However, do not be put off as you will hear and work many stations although you may need to pay more attention to your operating skill and take full advantage of the conditions as previously mentioned. A better equipped station will probably hear stations on a band before you and will be able to hear them after they have faded at your station, so make full use of the time that you are able to hear them!

The following table is a guide to the areas that it should be possible to hear given favourable conditions. This is based on observations with average to fair conditions during the late Autumn. 30, 17 and 12m tend to have characteristics of both the band below and the band above and are always worth checking as they tend to have less stations causing interference, so it may be possible to hear stations that might be blocked out on a busier band. 10MHz is a CW and data only band (although SSB is not illegal, it is highly frowned on as the band is only 100kHz wide). Much DX can be worked on these bands, and as many countries have power or antenna limitations, there is much less risk of being beaten by a powerhouse signal as very often happens on the other bands (as an example, stations in the USA regularly run 1.5kW into stacked multi element yagi arrays at heights of 30m or more, which makes your 10 or 100w into a dipole look rather humble!).

Propagation though is a great leveller and understanding how the bands respond at different times of the day and year will tip the scales in your favour.

BAND	FREQ	EARLY AM	MID-LATE AM	EARLY PM	MID-LATE PM	EVENING	NIGHT
160m	1.8 MHz	Americas, West Africa, Australasia	UK	UK	UK, Europe, Pacific, East Asia, East Africa	Europe, Australia, Asia, Africa	Europe, Americas, ME
80m	3.5 MHz	Americas, West Africa, Australasia	UK, near Europe	UK, near Europe	UK, Europe, Pacific, East Asia, East Africa	Europe, Australia, Asia, Africa	Europe, Americas, ME
40m	7 MHz	Americas, West Africa, Australasia	UK, near Europe	UK, near Europe	UK, Europe, Pacific, East Asia, East Africa	Europe, Australia, Asia, Africa	Europe, Americas, ME
30m	10 MHz	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓
20m	14 MHz	Europe, West Africa, South America, Pacific and Far East	Europe, Australia, Pacific, West Africa and South America	Europe, Alaska, East USA, Pacific and Asia.	Europe, Asia, Australia, East Africa, West USA	All continents.	Band tends to close at night but communication may still be possible with Europe and the Americas
17m	18 MHz	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓
15m	21 MHz	Europe and Russia, East Africa, North Eastern Asia, possibly Pacific and West USA	East Europe, Japan, Far East, New Zealand and Australia, West Africa and South America	Australia, East Europe, East USA	Europe, Australia, South East Asia, Africa and Americas.	Europe, Africa, Americas and possibly Hawaii	Band Closed
12m	24 MHz	↑↓	↑↓	↑↓	↑↓	↑↓	↑↓
10m	28 MHz	East Europe, Russia, East Africa, Indian Ocean, possibly Pacific and West USA	Australia, Asia and Africa, later South America	South and South East Asia, Europe, Americas.	North America, Africa, South Asia, possibly Hawaii	Americas, particularly South America. Possibly East Australia	Band Closed

It should be noted that signals on 1.8MHz will tend to be weaker and the openings shorter than on 3.5MHz. The openings on 7MHz will, in turn be stronger and last longer than those on 3.5MHz. This is due to the lessening effect of absorption with increasing frequency. During the summer months, with increased amounts of daylight, the higher bands tend to stay open much later and open earlier. 14MHz in particular can stay open for the full 24 hours. It is always worth checking closely a band that appears to be dead as many surprises can be heard!

#### WHAT IS THE NCDXF / IARU BEACON CHAIN?

The NCDXF (Northern California DX Foundation) and the IARU (International Amateur Radio Union) operate a series of beacon stations that transmit 24 hours a day, 7 days a week on spot frequencies with the sole purpose of allowing propagation studies to be made. The frequencies these beacons use are: 14100, 18110, 21150, 24930 and 28200kHz. Each beacon transmits it's callsign (in Morse code at 22 words per minute) followed by a series of tones at varying power levels. The callsign and first tone are sent at 100W, the subsequent tones are sent at 10W, 1W and finally 100mW (0.1W). It is amazing how many beacons can be heard at all power levels. The beacons follow a 3 minute repeat pattern, so each beacon will transmit once on each frequency every 3 minutes. As these beacons are located all over the world it is likely that you will only be able to hear a few of them at any one time. All the beacons use the same equipment, which is a 100w transmitter and a multiband vertical antenna (to imitate an average amateur transmitting station). With many different beacons and locations, the NCDXF beacon chain has to be carefully coordinated otherwise total confusion would reign if a new beacon popped up without being properly integrated into the chain. Below is the complete list of NCDXF beacons, with location and operating schedule. The time shown below each frequency column is the position within the 3 minute segment that the corresponding beacon transmits. A useful software program called "BeaconSee" automatically monitors these beacons and gives a graphical display of what can be heard. If your radio supports computer control, the program will switch frequencies to track the various beacons.



<b>CALLSIGN</b>	<b>LOCATION</b>	<b>14.100</b>	<b>18.110</b>	<b>21.150</b>	<b>24.930</b>	<b>28.200</b>
4U1UN	United Nations (New York)	00:00	00:10	00:20	00:30	00:40
VE8AT	Canada	00:10	00:20	00:30	00:40	00:50
W6WX	United States (California)	00:20	00:30	00:40	00:50	01:00
KH6WO	Hawaii	00:30	OFF	00:50	OFF	01:10
ZL6B	New Zealand	00:40	00:50	01:00	01:10	01:20
VK6RBP	Australia	00:50	01:00	01:10	01:20	01:30
JA2IGY	Japan	01:00	01:10	01:20	01:30	01:40
RR9O	Russia (West Siberia)	01:10	01:20	01:30	01:40	01:50
VR2B	Hong Kong	01:20	01:30	01:40	01:50	02:00
4S7B	Sri Lanka	01:30	01:40	01:50	02:00	02:10
ZS6DN	South Africa	01:40	01:50	02:00	02:10	02:20
5Z4B	Kenya	01:50	02:00	02:10	02:20	02:30
4X6TU	Israel	02:00	02:10	02:20	02:30	02:40
OH2B	Finland	02:10	02:20	02:30	02:40	02:50
CS3B	Madeira	02:20	02:30	02:40	02:50	00:00
LU4AA	Argentina	02:30	02:40	02:50	00:00	00:10
OA4B	Peru	02:40	02:50	00:00	00:10	00:20
YV5B	Venezuela	02:50	00:00	00:10	00:20	00:30

Hopefully the preceding pages have given an insight into propagation as encountered on the MF and HF bands. If you apply this knowledge of propagation techniques to your time on the air, some really spectacular results can be achieved by stations running very simple equipment and low powers.

Some lesser known terms that are sometimes heard in conversation: Sporadic D (D's), Sporadic F (F's), Electron Gyrofrequency Absorption and Quasi Biennial Oscillations. These are terms used when exploring propagation in greater depth and an explanation is beyond what is trying to be achieved with this article.

The somewhat different methods used to propagate signals at VHF and above will be covered in a separate article.