THE VLF STORY

A LISTENER'S STORY ABOUT ELF/VLF "NATURAL RADIO" EMISSIONS OF EARTH IN THE 0.1 TO 10 kHz FREQUENCIES.

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Authors forward: This story was originally written for the book *A Whistler Serenade* from Stonehenge Viewpoint Press (1995) at the invitation of the publisher in early 1995. A fair portion of that book discussed various theories on Crop Circles and the even more complex pictograms that were appearing in rapidly increasing numbers in English wheat (and other crop) fields throughout central/southern England. Donald Cyr, publisher and co-author of *A Whistler Serenade*, was fascinated by these beautiful circles and the various other shapes of the pictograms, and he along with friend and partner James Brett conjectured many scientific and pseudo-scientific theories about them, including one theory that they were being caused by whistlers. While I really didn't believe whistlers were their cause (from what I knew about whistlers and VLF radio waves in general), I was keeping an open mind as well as offering my very gentle and good-natured refute of Cyr and Brett's "Whistler-Crop Circle Theory." Therefore, please bear this in mind when you come across mention of Crop Circles later on in this writing that it was discussed within this context.

Secondly, there have been many findings since the classical "magneto-ionic duct theory" pertaining to whistler generation was developed by R. Heliwell in the late 1950's. This has to do with the travel of whistler-mode electromagnetic waves along magnetic lines-of-force from the source lightning stroke to the opposite hemisphere to be heard as a "one-hop whistler." Conjugate points were thought to be rather fixed, but anecdotal observations by listeners such as myself and also more detailed scientific studies and analysis of whistler-mode waves tell give a much more dynamic picture of Earth's magnetic-field. Please refer to the section about this and Kimura's writing further down in this piece. - *S. P. McGreevy, 12 October 1997*

Relatively few people know of (and even fewer have heard) the beautiful radio "music" produced naturally by several processes of nature including lightning storms and aurora, aided by events occurring on the Sun. I have been fascinated with listening to naturally-occurring radio signals since about the middle of 1989, hearing my first whistlers almost immediately after first trying out a rudimentary receiving apparatus I had put together for the occasion.

Whistlers, one of the more frequent natural radio emissions to be heard, are just one of many natural radio "sounds" the Earth produces at all times in one form or another, and these signals have caught the interest and fascination of a small but growing number of hobby listeners and professional researchers for the past four decades.

"Natural Radio," a term coined in the late 1980's by California amateur listener and researcher Michael Mideke, describes naturally-occurring electromagnetic (radio) signals emanating from lightning storms, aurora (The Northern and Southern Lights), and Earth's magnetic-field (the magnetosphere).

The majority of Earth's natural radio emissions audible with ground-based radio receivers occur in the extremely-low-frequency and very-low-frequency (ELF/VLF) radio spectrum - specifically, at AUDIO frequencies between approximately 100 to 10,000 cycles-per second (0.1--10 kHz). Unlike sound waves which are vibrations of air molecules that our ears are sensitive to, natural radio waves are vibrations of electric and magnetic energy (radio waves) which - though occurring at the same frequencies as sound - cannot be listened to without a fairly simple radio receiver to convert the natural radio signals directly into sound.

Whistlers are magnificent sounding bursts of ELF/VLF radio energy initiated by lightning strikes which "fall" in pitch. A whistler, as heard in the audio output from a VLF "whistler receiver," generally falls lower in pitch, from as high as the middle-to-upper frequency range of our hearing downward to a low pitch of a couple hundred cycles-per-second (Hz). Measured in frequency terms, a whistler can begin at over 10,000 Hz and fall to less than 200 Hz, though the majority are heard from 6,000 down to 500 Hz. Whistlers can tell scientists a great deal of the space environment between the Sun and the Earth and also about Earth's magnetosphere.

The causes of whistlers are generally well known today though not yet completely understood. What is clear is that whistlers owe their existence to lightning storms. Lightning stroke energy happens at all electromagnetic frequencies simultaneously--that is, from "DC to Light." Indeed, the Earth is literally bathed in lightning-stroke radio energy from an estimated 1,500 to 2,000 lightning storms in progress at any given time, triggering over a million lightning strikes daily. The total energy output of lightning storms far exceeds the combined power output of all man-made radio signals and electric power generated from power plants.

Whistlers also owe their existence to Earth's magnetic field (magnetosphere), which surrounds the planet like an enormous glove, and also to the Sun. Streaming from the Sun is the Solar Wind, which consists of energy and charged particles, called ions. And so, the combination of the Sun's Solar Wind, the Earth's magnnetosphere surrounding the entire Planet, and lightning storms all interact to create the intriguing sounds and great varieties of whistlers.

How whistlers happen from this combination of natural solar-terrestrial forces is (briefly) as follows: Some of the radio energy bursts from lightning strokes travel into space beyond Earth's ionosphere layers and into the magnetosphere, where they follow approximately the lines-of-force of the Earth's magnetic field to the opposite polar hemisphere along "ducts" formed by ions streaming toward Earth from the Sun's Solar Wind. Solar-Wind ions get trapped in and aligned with Earth's magnetic field. As the lightning energy travels along a field-aligned duct, its radio frequencies become spread out (dispersed) in a similar fashion to light shining into a glass prism. The higher radio frequencies arrive before the lower frequencies, resulting in a downward falling tone of varying purity.

In this manner, a whistler will be heard many thousands of miles from its initiating lightning stroke--and in the opposite polar hemisphere! Lightning storms in British Columbia and Alaska may produce whistlers that are heard in New Zealand. Likewise, lightning storms in eastern North America may produce whistlers that are heard in southern Argentina or even Antarctica. Even more remarkably, whistler energy can also be "bounced back" through the magnetosphere near (or not-so-near) the lightning storm from which it was born! There will be additional discussion of this "theory of whistlers" in the next few pages.

Considered my many listeners to be the "Music of Earth," whistlers are amongst the accidental discoveries of science. In the late 19th century, European long-distance telegraph and telephone operators were the first people to hear whistlers. The long telegraph wires often picked up the snapping and crackling of lightning storms, which was mixed with the Morse code "buzzes" or voice audio from the sending station. Sometimes, the telephone operators also heard strange whistling tones in the background. They were attributed to problems in the wires and connections of the telegraph system and disregarded.

The first written report of this phenomenon dates back to 1886 in Austria, when whistlers were heard on a 22-km (14 mile) telephone wire without amplification. A paper by W.H. Preece (1894) appearing in Nature Magazine describes operators at the British Government Post Office who listened to telephone receivers connected to telegraph wires during a display of aurora borealis on March 30 & 31, 1894. Their descriptions suggest they heard whistlers and the "bubbling/murmuring" sounds of "Chorus" from aurora.

During World War I, the Germans and Allied forces both employed sensitive audio-amplifiers to eavesdrop on the enemy's telephone communications. Metal stakes were driven into the ground next to enemy telephone wires and were connected to tube-type high-gain amplifiers, whereby the audio signal in the telephone wires could be eavesdropped. This early form of electronic espionage worked fairly well most of the time, despite the bubbling and crackling background noise made by lightning--but not always.

On some days, the telephone conversations they were eavesdropping on were partially or wholly drowned out by strange whistling sounds. Soldiers at the front would say, "you can hear the grenades fly." These whistling sounds, described as sounding almost like "piou," were at first attributed to the audio amplifiers' circuitry reacting adversely to strong lightning discharge noises. When laboratory tests on the high-gain audio amplifiers failed to recreate the whistling sounds, the phenomena was then considered "unexplainable" at that time. (H. Barkhausen, 1919).

In 1925, T. S. Eckersly of the Marconi Wireless Telegraph Company in England, described disturbances of a musical nature that had been known to "radio" engineers for many years. They were heard when a telephone or any other "audio-recorder" system was connected to a large aerial. What they were hearing are now known as "tweeks," a common ringing and pinging sound that lightning discharge radio energy (sferics) atmospherics sound like at night with a VLF receiver or audio amplifier. Several people began to observe how lightning and auroral displays coincided with many of the strange sounds they were hearing with their audio apparatus (Barkhausen, Burton, Boardman, Eckersly, et al.).

In the 1930's, the relationship of whistlers and lightning discharges was hypothesized, and in 1935, Eckersly arrived at the commonly accepted explanation that lightning initiated radio waves traveling into Earth's "ionosphere" caused these tweek sounds. They were getting "close." Interest in whistlers waned during World War II but was renewed with the development of sound spectrographs and spectrum analyzers, which could trace the time-versus-frequency component of audio sounds. This technology was developed mainly for the study of the sound characteristics of speech and other sounds, but these also were fine tools for the exploration of whistlers, as well (R. K. Potter, 1951).

It was during this time that L.R.O. Story in Cambridge, England, had begun an in-depth investigation into the nature and origin of whistlers. Armed with information presented by Barkhausen, Boardman, et al., a homemade spectrum analyzer and other audio- frequency radio equipment, Storey studied whistlers in earnest, discovering several types of whistlers that were or were not audibly associated with lightning discharge "clicks" in the receiver. He was able to make graphs of many kinds of whistlers, forming the basis of the modern "magneto-ionic" theory of their origin, and also the effects of Earth's magnetic storms on whistlers.

Storey's conclusion that whistlers were formed by lightning discharge energy echoing back and forth along the lines-of-force of earth's magnetic field suggested that there was a much higher than expected ion density in the outer ionosphere and beyond, and that the source of this "extra" ionization was linked to the sun. He also (correctly) presumed these ions from the sun also were responsible for magnetic storms and auroral displays. Story, while mainly concentrating on whistlers, was able to hear and categorize a number of other audio-frequency emissions that he heard, including Dawn Chorus, steady hiss, and certain "rising whistlers," also known as "risers".

Story's studies throughout the early-to-mid 1950's made an important contribution to whistler theory by showing that whistlers travel very nearly in the direction of Earth's magnetic field. In 1952, the results of Storey's work were presented by J. A. Radcliffe to the Tenth General Assembly of the URSI held in Sydney Australia, exciting considerable interest among the delegates in attendance. Radcliffe's report greatly stimulated whistler research at Stanford University, headed by the "Father of Whistler Research," R. A. Helliwell.

In 1954 at the next URSI General Assembly held in the Hague (Netherlands), whistler theory was discussed in depth, and plans were devised to study whistlers at opposite "conjugate" points of Earth's magnetic field. Lightning storm atmospherics observed in one hemisphere were heard as "short whistlers" (1-hop whistlers) in the opposite hemisphere. This notable observation was conducted by Helliwell at Stanford in California and aboard the U.S.S. Atka located in the South Pacific near the opposite magnetic conjugate point. Lightning storms generating atmospheric static "pops" as heard in the ship's onboard VLF receivers were heard nearly simultaneously in Stanford as short whistlers.

Even more verification of Storey's whistler was confirmed by the observation of whistler "echo trains" simultaneously heard in Alaska and in Wellington, New Zealand, which lies at the opposite magnetic conjugate from Alaska. With this generalized history of whistler discovery and research in mind, I should pause this history lesson and now explain whistler theory in somewhat greater detail.

The generally accepted theory of whistlers (Storey, Morgan, Helliwell) is as follows (the following few paragraphs are taken directly from the text of my WR-3 "Whistler Receiver" Listening Guide and repeat some information presented earlier in this article as well as hopefully making clearer some terms I've been tossing about): The Earth's outer magnetic field (the "magnetosphere") envelopes the Earth in an elongated doughnut shape with its "hole" at the north and south magnetic poles. The magnetosphere is compressed on the side facing the Sun and trails into a comet-like "tail" on the side away from the Sun because of the "Solar Wind" which consists of energy and particles emitted from the Sun and "blown" toward Earth and the other planets via the Solar Wind. Earth's magnetosphere catches harmful electrically charged particles and cosmic rays from the Sun and protects life on Earth's surface from this lethal radiation.

Among the charged particles caught in the magnetosphere are ions (electrically charged particles), which collect and align along the magnetic field "lines" stretching between the north and south magnetic poles. These magnetic-field aligned ions bombarding Earth's magnetosphere form "ducts" which can channel lightning- stroke electromagnetic impulse energy. Whistlers result when an electromagnetic impulse (sferic) from a lightning- stroke enters into one of these ion-ducts formed along the magnetic lines of force, and is arced out into space and then to the far-end of the magneto-ionic duct channel in the opposite hemisphere (called the opposite "magnetic conjugate"), where it is heard as a quick falling/descending emission of pure note tone or maybe as a brief "swish" sound.

Whistlers sound the way they do because the higher frequencies of the lightning-stroke radio energy travel faster in the duct and thus arrive before the lower frequencies in a process researchers call "dispersion." A person listening with a VLF receiver like the WR-3 in the opposite hemisphere to the lightning stroke (at the far end of the Magnetospheric duct path) will hear this "short" or "1-hop" falling note whistler. One-hop whistlers are generally about 1/3 of a second to 1 second in duration. If the energy of the initial short/1-hop whistler gets reflected back into the magneto-ionic duct to return near the point of the originating lightning impulse, a listener there with a VLF receiver will hear a "pop" from the lighting stroke impulse, then roughly 1 to 2 seconds later, the falling note sound of a whistler, now called a "long" or "2-hop" whistler.

Two-hop whistlers are generally about 1-4 seconds in duration depending on the distance the whistler energy has traveled within the magnetosphere. One-hop whistlers are usually higher pitched than two-hop whistlers. The energy of the originating lightning stroke may make several "hops" back and forth between the northern and southern hemispheres during its travel along the Earth's magnetic field lines-of-force in the magnetosphere. Researchers of whistlers have also observed that the magnetosphere seems to amplify and sustain the initial lightning impulse energy, enabling such "multi-hop" whistlers to occur, creating long "echo trains" in the receiver output which sound spectacular! Each echo is proportionally longer and slower in its downward sweeping pitch and is also progressively weaker. Conditions in the magnetosphere must be favorable for multi-hop whistler echoes to be heard. Using special receiving equipment and spectrographs, whistler researchers have documented over 100 echoes from particularly strong whistlers--imagine how much distance the energy from the 100th echo has traveled--certainly millions of miles!

Generally, only one to two echoes are heard if they are occurring, but under exceptional conditions, long "trains" of echoes will blend into a collage of slowly descending notes and can even merge into coherent tones on a single frequency, hard to describe here, but quite unlike any familiar sounds usually heard outside of a science-fiction movie!

Back to the history of whistler research. Plans for studying whistlers, chorus, and other audio-frequency natural radio phenomena were formulated by Dr. J. G. Morgan of the University of New Hampshire in Hanover as well as Dr. Helliwell at Stanford, for the International Geophysical Year which would begin in 1957. Over 50 receiving stations were set up at many locations all over the globe, including remote locations in northern Canada, Alaska, Europe including Scandinavia, and even Antarctica. This period was the beginning of the most intensive professional study of whistlers ever.

In the early 1960's, a couple of satellites (IEEE-1, Injun, Allouette) destined for low Earth Orbit were outfitted with VLF receivers. These satellite-based VLF radio receivers successfully recorded whistlers, and greatly enhanced scientific knowledge of natural VLF radio emissions. During the 1970's, space probes, such as Pioneer and Voyager, would discover whistlers happening on other planets of our Solar System, such as Jupiter and Saturn, which both have enormous and powerful magnetospheres. These Gas Giants also have huge magnetospheres and their own polar aurora as well.

The 1980's saw increasing hobbyist and amateur observations of whistlers, thanks to the increasingly easy availability of solid- state electronic parts and VLF receiver construction articles and notes. By 1985, whistler articles and receiver designs would appear in several electronic and radio hobbyist magazines, and also radio club bulletins - most notably, the Longwave Club of America's monthly bulletin, THE LOWDOWN. Several LWCA members including Michael Mideke, Mitchell Lee, Ev Pascal, Ken Cornell, and others, would publish and or design and use their own successful whistler receiver versions. These hobbyist whistler receivers tended to use small loop or wire antennas, unlike the "professional" VLF receivers used during the late 50's and early 1960's, which used very large loop and/or tall vertical "pole" antennas.

One radio "mentor" who sparked my fascination with whistlers and Natural Radio is a gentleman named Michael Mideke, who has been an avid enthusiast involved in various esoteric radio (and non- radio) pursuits since the early 1970's. Mike taught me quite a considerable amount of knowledge about longwave radio receiving and transmitting experimentation at radio frequencies much higher than Natural Radio, and he himself began regularly monitoring Natural Radio about the middle of 1988, more than a year before I would hear my first whistler in the Oregon desert.

For the past 25 years, Mike, his wife Elea, and two sons lived as caretakers on a large ranch in a remote central California canyon, far from electric powerlines. Here, Mike was able to string out antenna wires over thousands of feet in length and running in several different compass directions, and connect them to his plethora of radio receivers. His remote, electrically-quiet location was also ideal for listening to whistlers. Over the years, Mike has also made many hundreds of hours of recordings of amazing radio sounds of the Earth. He was particularly fortunate to be able to monitor 24 hours a day during the height of the sunspot cycle - from 1989-1991 - when solar activity, geo-magnetic disturbances, and whistlers were most numerous.

Mike also passed along the results of his own receiver experimentation, thus positively influencing my own receiver experimentation. In late summer of 1990, I began experimenting with whistler receivers employing short "whip" antennas no longer than 5 to 6 feet in length. These "whip receivers" successfully monitored whistler activity, though my earliest versions lacked sensitivity.

I must credit the original idea of using a short whip antenna to a longtime close friend and fellow whistler enthusiast, Gail West, who lives in Santa Rosa, California and has accompanied me on many of my road trips and whistler listening expeditions. Gail repeatedly witnessed my frustration with stringing out unwieldy wire antennas, and on one particular morning (summer 1989) in the northern Nevada desert, commented "it sure would be nice to use just a small whip antenna rather than long wires for a whistler receiver antenna."

Also, while on a solo listening session in the hills of Marin County, California in February 1990, I heard a strong whistler howl from the tape recorder's speaker with nearly all but about 10 feet of antenna wire rolled back onto the spool. This experience reminded me of Gail's idea and made the whip antenna idea seem more plausible. While the idea of a hand-held whistler receiver seemed somewhat wishful thinking early on in my experimentation with whistler receivers, it would become reality in just over two years of whistler listening and receiver tinkering.

Increasingly better and more sensitive yet simpler whip antenna whistler receivers were continuously devised on my workbench. On a beautiful spring morning in May 1991 while hiking on a trail in the mountains east of San Diego with friend Frank Cathell of Conversion Research, I demonstrated my BBB-2 whip antenna whistler receiver. Frank was so fascinated with this receiver that he jumped on the bandwagon, and by August 1991 after a furious 3 months' of receiver tinkering, Frank and I created a sensitive battery-powered whistler receiver that required only a small 33-inch antenna, was cigarette pack sized and very portable, called the "WR-3," and we shortly began selling this new pocket receiver on a casual basis.

The WR-3 opened up whistler monitoring to practically everyone--even non-technical people--willing to at least undertake the effort of finding a reasonably powerline "hum" free location where whistlers and other natural VLF radio phenomena could then be listened to and enjoyed as easily as listening to regular broadcast radio. At this point thanks to the WR-3, whistlers and lightning sferics were very easy to hear--now it was just up to Mother Nature to put on a show.

My difficulties with whistler receivers and antennas were now behind me, but I still retain very fond memories of the beginnings of my own interest in whistler listening and study. In June 1989, Gail and I heard our first whistlers "live" while camped deep in the eastern Oregon desert near Steens Mountain. In anticipation of the trip and not yet aware of more advanced receiver circuits available for this pursuit, I built a crude "whistler-filter" which I knew would at least block out a lot of the potential man-made signals which might overload my tape- recorder's audio-amplifier.

During the days leading up to desert trip, Summer thunderstorms had been plaguing the Great Basin areas of central and northern Nevada--the result of the typical summertime "monsoonal" moisture which sometimes gets driven up northward from the southwestern states of Arizona and

New Mexico toward the inter-mountain region of the western U.S. (including Utah and Nevada). July and August are the months of the most spectacular lightning storm displays that pound almost daily throughout the deserts and mountains of western North America.

As Gail and I arrived at our intended campsite in the Black Rock Desert of northern Nevada, one of the more fiercer-looking cumulonimbus clouds drifted in our direction, and a light rain began to patter the parched desert dirt. Shortly thereafter, the wind picked up accompanied by the rumble of thunder. It looked like we were going to be in for quite a bit of this judging by the looks of the clouds. As we tried to set up our "Tahjmatent"--a huge dome tent which was tall enough to stand up in and roomy enough for 10 people to sleep in--the winds started to blow so hard all Gail and I could do was just stand there holding the now horizontally flailing tent.

The situation seemed rather dismal, however the skies to the north looked almost cloud-free, so we decided to cram our big wad of a tent and other supplies back into my small Toyota coupe and head farther north to an alternate location in Oregon about 100 miles away. We would return to the Black Rock Desert the following month under clear skies.

Arriving in the Alvord Desert of south-eastern Oregon with about 1 1/2 hours of sunlight left, we set up the tent under clear blue skies while occasionally stealing glances at the still ominous-looking skies to the distant south, hoping it would not come up our way. Fortunately, we were spared any further harassment from the weather and I became confident I could unroll my nearly 500 meter-long wire across the sagebrush. I connected my whistler filter to this wire and "grounded" the other connection to the car. Connecting my tape-recorder to the filter, I was rewarded by loud snapping and crackling from all the lightning happening south of us.

The following morning at sunrise under cloudless skies, I turned on the tape-recorder and listened to the now greatly reduced amount of lightning static. But, a few of the louder lightning "pops" had whistlers (or what I thought sounded like "whizzers") happening a second or two afterward! I shouted for joy and thrust the headphones at Gail for her to listen, too. We were hearing our first whistlers, though they sounded different from the few I had heard recorded on cassette tape by Michael Mideke back in central California. The whistlers went on for an hour or so then died away.

The following morning, the whistlers were back, but even louder! An already very enjoyable desert trip had turned into a milestone for me! Now that I had heard whistlers on my own, I became "hooked" with this very esoteric aspect of radio listening. I had been enjoying shortwave listening to stations around the world and amateur "ham" radio for the past dozen years, but this was something very new and fascinating - something that played well into my other casual and hobby interests in geo-physics, meteorology, and radio wave propagation studies.

Over the next few years, I would learn a great deal about natural radio phenomena and how to build excellent receiving equipment to listen for whistlers and the like. One of my main goals was to build a whistler receiver that would not require a whole roll of antenna wire but only a small whip antenna - a desire which came to fruition in the spring of 1990, when I "accidentally" heard a loud whistler while rolling up the final few meters of antenna wire. I knew it was possible to hear whistlers with small antennas, and as I've already mentioned, a prototype to my portable hand-held "WR-3" receiver was devised a in the spring of 1991 with the help of another radio friend, Frank Cathell of Conversion Research.

In addition to all of my whistler receiver tinkering, trials and successes mentioned above, serious and regular natural radio listening (and quality recordings) began in February 1991, when nearly every Sunday morning well before sunrise (the "prime time" to listen for whistlers), I would pack my favorite whistler receiver, a small reel-to-reel tape recorder, and lunch into a knap sack and bicycle to the nearby hills. Upon reaching the base of the hills, I would then dismount and walk the bike up via a fire access-road to my favorite listening spot--a flat ridge-line overlooking much of Marin County, San Francisco, and San Pablo Bay at an elevation of about 600 feet above sea-level--which I began calling "Whistler Hill." There, I would listen for whistlers, and if there were any happening, run the tape recorder. I was rewarded by many beautiful sunrises and many nice whistlers on my weekly visits to Whistler Hill, and I was quite happy with my current receiver, a unit which used a 66-inch whip antenna, called the "MC-1."

One memorable morning near Easter 1991, a "huge" whistler--the loudest of the morning--occurred just as the sun began peeking above the north- northeastern horizon. It was in this year that I would really discover the aesthetic beauty of whistler listening while out in nature! While I was always glad to hear whistlers in the hills, it was not always easy to awake at 4 a.m. in the cold and bicycle the few miles up to Whistler Hill. Many of those Sunday mornings would have been better spent sleeping a few hours longer, but Oh!, was I so glad when those whistlers would be pouring forth in my receiver's headphones as another gorgeous sunrise was forthcoming--then I was always glad I made the effort to get up early! But then again, I would sometimes get up to Whistler Hill only to hear NOTHING except the ever-present crackling of Earth's ongoing electrical storm commotion. And if the weather was gloomy, I was usually tempted to ride back home instead of continuing on my usual 8-10 mile bike and hike.

Why DIDN'T I stay home and listen to whistlers from the comfort of my bed, as is generally possible with more conventional broadcast radio? The problem lies with the electric-mains grid which has spread nearly every place man has settled. Alternating-current electric power lines emit "hum" at 60 cycles- per-second in the Americas, and 50 c.p.s. (Hz) in Europe and Asia. In addition to these "fundamental" AC power frequencies, "harmonic" energy is also radiated (120, 180, 240, 300, 360 Hz, etc.), or as in Europe and Asia: 100, 150, 200, 250, 300 Hz, etc.)- often to well above 1 or 2 kHz. Since whistler receivers are sensitive to these electric power frequencies, any natural radio events which might be occurring get masked by this terribly annoying humming sound, should one try to listen anywhere near AC powerlines.

The only solution to AC power-line "hum" is to locate a listening spot away from AC power poles and wires--often as far as several miles before the hum levels are reduced to low or nil levels. This necessitates walking, hiking, bicycling, or driving to remote locations where there are few or no AC power lines - easy to do in many parts of California and the West but often very difficult in flat land or urban locales. Sometimes--and with good filters in the whistler receiver--one can listen as close as a couple-hundred feet (or maybe even closer) to residential AC electric wires.

On a few fortunate and astounding occasions, whistlers can get so loud as to even be heard through the loud power-line hum levels encountered in a suburban backyard, demanding the whistler listener to immediately relocate to their favorite "quiet" listening spot in order to hear and tape record such magnificently giant whistlers, and at the same time praying that the monster whistlers still are going on when the whistler receiver is again turned on! Murphy's Law and my experiences generally suggest they will be gone and not to return until another inopportune time...

My tape libraries of whistlers and other natural radio phenomena vastly increased in late 1992 and throughout 1993 and early 1994. The stimulus to get out and make natural radio recordings came when, after purchasing a "camper-van" in July 1992, Gail and I headed up California's North Coast, stopping for the night at Westport Union Landing Beach north of Fort Bragg. We heard nice whistlers that evening and morning during darkness using our WR- 3's clamped in the van's rear doors while laying in our comfy beds.

Occasionally, however, one or both WR-3's would slip out of the door and nearly hit our heads. Gail came up with an idea to have a whistler receiver with an antenna that could remain outside while a control box could be put next to the beds. Well, I got right to work on this great idea of hers upon returning home, and quickly designed an excellent "WR-4" whistler receiver in which the receiving antenna (2.5 meters in length) is mounted on the van's read door ladder and the control-box containing filter switches, headphone and tape-recorder jacks, etc. could be placed next to the bed! Now, I could make recordings while comfortably in bed, even while dozing off - letting the recorder run for 45 minutes or until I awoke to monitor the situation.

Since recording became very "convenient" while camping -no more sore arms holding the receiver out the window or standing out in the cold and win, and not as much sleep deprivation as before--I (alone or with Gail) am now able to locate to superbly quiet camping/listening locations deep in the western deserts, the northern Plains of North America, or near mountainous areas and wait for conditions to present interesting natural radio sounds. The past couple of years has seen the combining of my enjoyment of camping and road trips with natural radio listening, culminating in the Summer 1996 SOLAR-MINIMUM VLF RECORDING EXPEDITION to northern Manitoba in late summer 1996 (and 30 hours of incredable natural VLF radio tapes!).

The ease of whistler listening with the van-based WR-4 and later, the WR-4b (additional LC filter circuit) and our love or camping trips has resulted in about a hundred hours of recording between 1993 and 1996 from over 25,000 miles of travel - a natural radio tape library which has become one of the better ones from an amateur, but I have no doubt that Mike Mideke's has to clearly be the FINEST amateur/hobby tape library in the world recorded from ONE location, since he LIVED in a quiet location free from strong powerline "hum" and has not had to travel to enjoy natural radio.

When Donald Cyr initially inquired in late 1994 if I would like to contribute some thoughts on whistler listening and experiences during the past couple of years since I last contributed material to his book*: America's First Crop Circle; Crop Circle Secrets Part 2,* I said "sure, I'd love to write something for your new book."

Don was interested in any information I might be able to offer, such as where the best places to hear whistlers are, or if I found any particular places that whistlers were consistently stronger than in other locations. I assume he was hopeful that my findings might tie in to his theory, which I'll call "The Marion Island- Wiltshire Plain Crop Circle Theory," (a name I have created for this article) that suggests whistlers--at least the ones which might have caused many English Crop Circles in the late 1980's and early 1990's--are highly localized phenomena that are launched at a given point, such as Marion Island in the south Atlantic Ocean, and are ducted via the magnetosphere along a line-of-force to the northern hemisphere, specifically, to southern England, where they, if they do not cause odd impressions in wheat fields of the Wiltshire Plain, will nonetheless be very LOUD indeed to one listening for them with a whistler receiver.

Don's theory, backed by his friend and colleague James Brett, was first presented to his readers in *CROP CIRCLE SECRETS, PART 1,* published in 1991 and highly recommended reading for this discussion as is *PART 2,* published in 1992. This particular book of Don's generated a good deal of interesting dialogue, and discussion. Of course, Don and James's Crop Circle Theory was really aimed at stimulating query and discussion about the what the mysterious forces which might be creating such incredible and beautiful impressions in the English landscape - and that is the true driving force of inquiry and research.

Other theories were pondered, suggested, debated, and dismissed by various contributors to Don's books, and they ranged from elaborate UFO theories, vortices and balls of light, military exercises (there are several military installations in that English region), underground forces of electromagnetic nature, to suppositions that they were plain and simply, artistic hoaxes concocted in the night by creative people armed with poles and chains.

Don and James were fascinated by the whistler theory as presented by researchers Storey Helliwell, The Institute of Radio Engineers (I.R.E.), et al., and they thought this theory was as good (if not better than most) at explaining a possible origin of Crop Circles. What seemed fascinating to Don and James was that Marion Island, also home to a secretive military installation, was at the far end of a magnetospheric duct, i.e., at a conjugate point to south-western England. Perhaps lightning storms, enhanced by the odd geography of Marion Island, or perhaps, a secret military experiment there, were generating great bursts of electromagnetic energy that would enter a magnetospheric field- aligned duct and arrive in England as a powerful whistler, which would cause Crop Circle by perhaps affecting the stems of the wheat stalks in odd manners.

From a scientific point of view, however--and from what both amateur and professional whistler listeners and researchers have found--it is hard to believe whistlers were so concentrated in their energy area and also "intelligent" to create such lovely patterns in the English fields. Radio engineers and other "technical" people involved with radio waves generally know that it is impossible to confine a radio wave to an area or volume less than 1/2 its wave length. In the case of whistler energy emerging from the confines of its duct and resuming the velocity of light

(300,000 km/186,000 miles per second), its (full-wave) size is from 19 miles at 10 kHz to almost 190 miles at 1 kHz--pretty large!

Mike Mideke eloquently expressed this reality in the final few paragraphs on page 27 and the first few paragraphs of page 28 of *CROP CIRCLE SECRETS. Part 2*. Also, the power of a radio wave (also known as the "field-strength") from even the strongest and loudest whistlers ever heard and/or recorded by anyone have never been as strong as the VLF radio waves generated from nearby lightning storms, though the lesser energy from whistlers is of course sustained much longer than the split-second burst of energy from a lightning stroke, and, or course, whistler radio energy does differ substantially from a lightning bolt's.

While whistlers would hardly seem to be so super-concentrated in their strength and focal area to cause such intricate and sharply defined impressions in plant material like crop circles, data gathered in the past 35 years by manned and un-manned monitoring stations located worldwide has found that whistlers do occupy a "footprint"--that is-they are heard loudest at a given location at ground level, and then gradually weaken as one moves concentrically away from "ground zero."

Most whistlers are heard in a 500 to 1000 mile radius from the exit point region of its duct, though it's sound characteristics may be different from one place to another within this whistler reception area. Whistlers also tend to cluster in the middle and upper-middle latitudes of the globe - between 25 and 60 degrees north/south, and are rarely heard at the "geomagnetic equator"--a wandering latitudinal line on the globe at the half way point of any great-circle line drawn from Earth's magnetic north pole to Earth's magnetic south pole.

Most of the continental United States and southern Canada are between these latitudes to hear not only splendid whistlers but also beautiful VLF radio "chorus" from Auroral displays. The same goes for most of Europe, especially the British Isles and Scandinavia.

In the Southern hemisphere; southern Argentina and Chile; the southern parts of Australia, particularly Tasmania; New Zealand; and perhaps, the Cape Horn region of South Africa, are similarly at the right latitudes to hear whistlers and chorus. The South Island of New Zealand and the Tierra del Fuego region of South America, plus the Antarctic Peninsula, are where the good displays of Aurora and auroral chorus can be seen and heard.

Listening to whistlers from near one's home town or on road trips can be very enjoyable and inspiring, but it is even more fun to travel abroad and check out whistler reception in other parts of the world. In late May of 1992, my father and I went on holiday to Ireland, enjoying a 12-day coach tour of the entire country. I brought my pocket-sized WR-3 whistler receiver, hoping to catch and record some "Irish whistlers."

The first night happened to be at the Clare Inn not far from Dromoland Castle and Newmarket-on-Fergus. Surrounding this hotel was a beautiful golf course, small lake, meadows, and woodlands. There were only a few powerlines near the hotel and main road to Ennis, leaving much of the golf course and meadowland fairly free from excessive Ac power hum, and therefore, good spots to listen for whistlers, as I tested out a few hours after we arrived bleary-eyed from an all night flight across the northern Atlantic.

In anticipation of hearing whistlers in this quiet and exotic location, I spent much of the pre-midnight period walking around with my Sony LW/MW/SW/FM radio, enjoying the Irish Radio Telefis Eireian (RTE) 1 & 2 radio networks, and the nighttime reception of British and European mediumwave (AM) stations, tape recording much of this reception with my trusty micro-cassette machine.

At around midnight, after the BBC on longwave 198 from Droitwich signed-off after the maritime weather report and a cheery "good night," I flicked on my WR-3. Lo and behold, there were nice whistlers, albeit only occasionally, since it still was a bit "early" for the really good whistler shows, which like to start up after 4 am. Catching some sleep in the woods (the hotel was rather far-off at this point) I awoke around 3 am, turned on the WR-3 to hear more whistlers--and there were LOTS of them, followed by weak "Auroral chorus" that rose up from the static at around 0400, and remained past my first Irish sunrise, when I drifted back to the hotel room to catch an hour or so of terribly-needed sleep!

That night would prove to be the only place our tour group would spend the night where there was open space - the rest of the hotels we stayed in would be located in towns or deep within Dublin, and surrounded by hundreds of electrical lines with no access to large open spaces. I had to be happy with broadcast listening with the Sony, which was always very interesting, anyway. It sure was great to now have natural radio recordings from outside the West Coast.

While scientists and hobby whistler listeners have pretty much determined what regions of Earth are in "whistler country," it is never possible to predict where, at any given time or on any given day, whistlers will be heard--loudly, weakly, or even at all. It's conceivable there are days where a whistler hardly occurs anywhere on the globe--undeniably there are days and even weeks when not a single whistler is heard by listeners located in otherwise ideal whistler reception regions of Earth, such as Ireland and Europe, the northern tier of the U.S., southern Canada, New Zealand, and so forth.

Conversely, there are days when there seem to be whistlers happening nearly everywhere, as though a giant switch was turned on somewhere in Earth's magnetosphere to issue forth a barrage of weak and strong whistlers too frequent to count! Like weather fronts and hurricanes, it would appear that given a day when things are ripe for strong whistler production, the locations that strong whistlers are heard constantly changes, depending on the locations of lightning storms; the magnetospheric whistler duct beginnings and end points; and the day/night region of the globe - particularly the midnight to 6 a.m. period - which, as we all know, moves westward 15 degrees an hour.

Thanks to simultaneous whistler monitoring and tape recording efforts, first by 1950's and 60's whistler researchers such as Storey, Morgan, Helliwell, etc.; and later by coordinated amateur and student study groups, hundreds of individual whistlers have been documented. Their findings have determined that the average whistler is heard in an area of about 500 miles radius, though the "big whoppers" may be heard as far as 2000 to 3000 miles from its loudest "arrival point."

One of my favorite examples of intense scrutiny of individual whistlers (by at least 25-30 listening groups or single monitors), was of "The Giant Whistlers" of the morning of March 28, 1992, specifically, of two whistlers occurring about an hour apart. In and of itself, these two huge whistlers are not really different from other strong whistlers which occur in the hundreds and maybe thousands throughout any season, but it WAS remarkable in that they were serendipitously caught on tape by so many listeners, who were participating in a high school student monitoring effort coordinated by a team of scientists and high school professors, called "PROJECT INSPIRE."

The INSPIRE effort was sanctioned by NASA to study the ground reception pattern of radio wave emissions from a special "modulated electron-beam" generator (called "ATLAS") aboard the Space Shuttle (STS-45), which flew in late March, 1992. A schedule of ATLAS "transmissions" was established in hopes that the ground-based VLF radio receivers set up by the student groups would hear its emissions. Unfortunately, the shuttle-based ATLAS unit failed after only two (unheard) transmissions. Fortunately, it was decided the students groups and other individuals should adhere to their INSPIRE listening schedule, and also to "backup" listening schedules arranged for the mornings of March 26-30, 1992. It was during many of these scheduled regular and backup listening periods that many interesting natural radio events were captured, including several strong and powerful whistlers.

A very detailed report entitled PROJECT INSPIRE DATA REPORT was produced in August 1992 by Michael Mideke, who was the project's data analyst. It is from this report where the following interesting scenarios of whistler reception has been interpreted. Back to the two "Giant Whistlers" of March 28, 1992. Bill Hooper, shivering at 4 a.m. Pacific time in his camper near California's Death Valley, started his tape recorders running once again. Bill was one of many experienced whistler enthusiasts who was monitoring individually but part of the larger INSPIRE student effort. He had set up one of the most sensitive whistler receiving stations--by far--of the entire group participating in the INSPIRE listening sessions, thanks in part to his remote desert location, great distance from any electric power lines combined with plenty of room for a large antenna and very sensitive whistler receivers of his own original design.

At precisely 4:02:38 a.m. PST, or 12:02:38 Universal (Greenwich Mean) Time, an extremely strong (long, 2-hop) whistler was recorded by Bill at his Death Valley listening site. So very strong was this whistler that it briefly overloaded Bill's receiving system. It also produced a "4-hop echo" which was also clearly recorded on his tape. This whistler was also heard and recorded as far away as the U.S. midwestern region and eastern seaboard, but much weaker and "truncated"--that is--only a fairly narrow spectrum of this huge whistler, in the 3-6 kHz range, propagated eastward. This whistler was also heard weakly to moderately in south-central Texas--but again--was somewhat truncated there like farther east. Interestingly, a large part of Texas was experiencing heavy rains and lightning storms- whistler receivers in southeastern Texas were picking up very strong, local-like lightning stroke "sferics."

If the source lightning of this whistler was in Texas, one wonders how it arrived so loud in the California desert! Perhaps it was generated by lightning strikes somewhere else, perhaps to the north or northeast of California, and far enough as to not really make much of an obvious sferic "pop" in the whistler receiver.

An hour later, a nearly identical strong whistler to the one at 12:02 UT occurred at 13:03:03 UT, this time heard by myself as well as Mike Mideke and others listening in Arizona New Mexico, and even Minnesota. Unlike the earlier big whistler, this particular whistler as heard in Minnesota was stronger. It also was not as "truncated" as was the earlier strong whistler. Interestingly, the sferic generated from the causative lightning stroke was rather weak in California, unlike its whistler.

Clearly, on this morning the big whistlers were concentrated in the western United States even though the lightning storms weren't. It should be noted there were days when the whistlers were stronger in the eastern United States and were weaker "out West," and point out how the locations of strong whistler activity change day-by-day and can't easily be tied to where lightning is happening. More on this in a bit.

While we are on the subject of loud whistlers and speculation on their originating lightning strokes, I have an anecdotal whistler story of my own to bring in at this point. While on our September 1993 "Big Trip" in my van and eventually to tour the Canadian provinces of Manitoba westward to British Columbia, Gail and I stopped in the eastern Nevada desert about 20 miles west of Wendover, Utah to catch several hours of sleep. Gail and I had driven most of the night across the Silver State after a brief stop the evening before at another favorite natural radio listening spot an hours's drive east of Reno, where we had heard and taped a marvelous variety whistlers, some very strong like the ones recorded by the INSPIRE listening groups in March 1992.

Very sleepy and exhausted after 250 miles east-bound on Interstate 80, we took a remote exit off the freeway and headed south down a wide, unpaved road running alongside some railroad tracks. In the dark, we noticed there were powerlines running along the train tracks, but determined to stop in a spot where we could get some sleep and record whistlers (which I was sure must still be roaring), we kept on going until we saw another smooth dirt road branching away at right angles away from the tracks and pesky wires. Making occasional checks for powerline hum with my WR-3, we drove far enough from the wires--at least 5 miles--to where I couldn't hear any hum with my WR-3 whatsoever. By this time, we were just too tired (and now cold) to even set up the better WR-4B whistler receiver's antenna. I just had enough energy to get in the back of the van and tuck myself under the covers, falling quickly asleep.

Awaking a few hours later, I noticed it was somewhat light with a slate-gray sky. Time to set up the WR-4's 10-foot copper-pipe antenna and check out the whistler band. As predicted, there were wonderfully loud "growler" type whistlers roaring out of fairly light background sferic static. I hopped back into bed and switched on my cassette recorder, capturing these great whistlers onto a 90 minute tape. My WR-4B whistler receiver was once again proving to be a truly superb receiver with its van- attached pipe antenna and convenient bedside control box, while the trusty WR-3 made a nice spot checking receiver. With the WR- 4B, I could snuggle under the covers and run tape - even if I fell asleep while recording. It certainly was a vast improvement over holding our WR-3's out the vehicle window or clamped in the van's door as we did that August 1992 night up the California Coast, and Mike Mideke even commented in a letter: "I was wondering when you'd get out of hand-held mode!"

This September 17, 1993 morning, Gail and I were having a nice time parked once again in the beautiful high desert surrounded by beautiful mountains, pungent sagebrush, whistlers roaring in the headphones, and few cares in the world. The entire 4,500 mile trip through 10 states and 4 provinces was completed in about 2 weeks and over 10 hours of natural radio recordings, including wonderful "auroral chorus" while watching the northern lights dance overhead in Alberta.

While many of my whistler and chorus tapes were recorded while tired, semi or fully asleep, I was not able to critically scrutinize what things I was recording until I got home. Herein lies the beauty of taping what you hear - events can be listened to again and again - in my case usually for the sheer beauty of Earth's natural radio sounds, but also for scientific analysis if necessary. Also, subtle events are sometimes missed while monitoring live due to fatigue, the distraction of beautiful surroundings, and so forth.

What I can explain about those great big eastern Nevada whistlers of September 17, 1993 is as follows: They were coming from rather weak but distinct and clean "tweeking pops," the kind which are produced by fairly distant ground strikes. Now, I've listened to a lot of lightning sferics while watching the lightning strikes making them, and the sounds of lightning static can be as varied as the visual strikes. I've noticed that the big, bright, single cloud to ground lightning strikes can deliver a very loud but clean "pop" in the whistler receiver's output. Cloud-to-cloud lightning, sometimes trigger other nearby in--cloud lightning, sounds more "crackly" or like the crushing of a Walnut in a nutcracker.

Anyway, interspersed amongst the numerous weak sferics and occasional, huge whistler generating popping tweek were occasional strong and semi-local lightning sferics - dry sounding and not tweeking - that were generating very weak and quite diffuse ("hissy") whistlers. These strong sferics were coming from lightning within about 50-100 miles of my listening location. Seems they just weren't generating big whistlers - or if they were, the whistlers were arriving SOMEWHERE ELSE strong but distant enough to explain their rather weak strengths near their source lightning. So, this idea of lightning stroke energy entering a duct or ducts to travel to the magnetic conjugate and then back again to the general area of their generating lightning strokes is a fairly simplistic explanation and not entirely satisfactory. And, as simplistic explanations tend to do, it fails to consider more complex events taking place...

It is my supposition that, somewhere, as they merrily arch along the magnetic-field lines, whistler ducts can cross, combine, and/or excite each other. In my mind this helps explain why 2- hop whistlers don't always "land" near where their originating lightning stroke occurred, but can wind up a thousand or more miles away! If you will, whistlers can "jump rail" and enter adjacent ducts, winding up curiously far from where they should arrive--whistler wanderlust.

As such, it is hard to believe southern England and Marion Island would have a dedicated whistler duct connecting them "together" and transferring Marion Island Lightning into Wiltshire whistler crop circles! More than likely, lightning energy from Marion Island winds up occasionally as a short whistler in southern England, but maybe an hour, day or week later, is sending whistlers into France, Spain, Iceland, or maybe Moscow - and these wandering whistlers are "bouncing back" as 2-hop whistlers now even more removed from their parent lightning storms!

I think conjugate points (and their associated "impact zones"), caused by variations in the exact position of Earth's magnetic field, can vary daily and even hourly--call it "conjugate end- point drift." If the solar wind is pushing against the magnetosphere, either gently - or as can be the case after solar flares and "coronal mass ejections" from the Sun - rather violently, then the motion of Earth's magnetic field lines and any whistler ducts present within them must also get tugged and pulled to various degrees from their "normal" positions. This--and my suggested whistler duct crossings, jumps, and re- combinations--must be partial explanations of why lightning in Texas sometimes causes strong 2-hop whistlers in California, or why Nebraska lightning generates huge whistlers in Manitoba that are weaker in Nebraska. Where was the Nevada lightning of the morning of September 17, 1993 sending strong whistlers (if any) to? Where were the rather weak lightning sferics that generated such giant eastern Nevada whistlers? I can also ask, just where was the lightning that spawned southern England's artistic whistlers?

One can't neatly package the fascinating whistler phenomenon with magnetic conjugate points, lightning stroke counts, fixed impact zones, et cetera, et cetera, and expect to easily explain what in reality is a mind-boggling dynamic process that changes like a kaleidoscope and never repeats.

While it is intriguing (and even fun) to try and scientifically unravel the phenomenon of whistlers, part of their allure is that they are just there to be listened to - they are as nice to hear as sunsets are to see, and the reasons for their existence must sometimes take a back seat to the beauty of their tones.

Neither myself or anyone else have yet to determine if there are "special places" where, perhaps due to local terrain or geology, whistlers are louder and more frequent than average. But, they may exist somewhere. Intriguingly, Edson Hendricks, a researcher into the mysterious "Marfa Lights," heard extremely loud whistlers issuing forth from a very crude and seemingly insensitive whistler receiver during a display of these strange and spooky colored balls of lights occasionally seen in the desert near Marfa Texas for nearly 50 years.

Ed was listening right near powerlines, and their "hum" would have surely been overpowering to more sensitive whistler receivers like my WR- 3, WR-4b or BBB-4, and also Mike Mideke's fine RS-3/4's, but Ed tells of these very pure whistler-like notes far stronger than the weakish background hum, as heard in the output of his simple receiver. Something is going on there in west Texas that needs further checking out, and it again points to the great need for more people to join in the whistler listening movement.

We would know vastly more about whistlers if there were as many people listening to whistlers as were watching the prime-time fare on television - a silly and hopeless wish - but even 100 or more people joining the whistler listening movement and coordinating listening schedules would give a clearer idea of when and where whistlers are coming and going. Whistler monitoring observations combined with information about where lightning storms and whistler source strikes were occurring would vastly help to exhibit this relationship. We could see if a pattern emerges or if things were more random with regards to location of the loudest whistlers and locations of their source lightning.

(Author's note: Long after I wrote this piece and surmised from my many years of listening to VLF and observing whistlers that magnetic field conjugate points were not really fixed on two given points in Earth's opposite hemispheres, such as Marion island and southern England, I came across an intriguing scientific paper in the American Geophysical Union's *Geophysical Monograph 53*, page 161, entitled *Ray Path's of Electromagnetic Waves in the Earth and in Planetary Magnetospheres*. This copyright 1989 paper written by Iwane Kimura of the Dept. of Electrical Engineering II, Kyoto, Japan, presents many graphs, mathematical formulae and diagrams of bi-polar magnetic field models of Earth showing wave-path tracings of man-made VLF signals transmitted from Siple Station in Antarctica and received by orbiting satellites. One particular paragraph written by in this article summarizes up nicely the potential for a great variability of whistler paths and conjugate points:

"For ray tracing of whistler mode waves in the earth magnetosphere, the simplest model of the geomagnetic field is a dipole model. Most of the ray tracing techniques treating wave phenomena in the earth magnetosphere have been based on the dipole model. Actually, however, real geomagnetic field lines are known to be fairly deformed from dipole field lines, so that for whistler waves, whose propagation are strongly governed by the geomagnetic field direction, ray paths calculated using the dipole model will differ considerably from those in the actual magnetosphere."

If whistlers aren't enough of a fascinating pursuit, there are a host of other natural radio "sounds" which can be heard at the 0.1-10 kHz audio-frequency portion of the radio spectrum to keep enthusiasts hooked on these Earth radio sounds. One of the more common (but less frequent than whistlers) are "chorus," which consists of a series of sharply-rising notes, called "risers." This fairly common phenomenon (but not as common as whistlers) can mimic the sounds of a flock of birds chirping, frogs croaking, or seals barking. Chorus occurs during magnetic storms, when Earth's magnetosphere receives a barrage of high- speed energetic particles cascading into it from solar flares on the Sun or from energy ejections from the Sun's "coronal holes" which allow to escape the Sun in streams traveling at sub-light speeds.

This phenomenon of magnetic storms is also responsible for the Aurora Borealis and Australis--the Northern and Southern Lights--seen in the sky at higher latitudes close to Earth's Arctic and Antarctic regions. Chorus can happen during visible aurora and is called "Auroral Chorus"--this sometimes can also be heard over a widespread area at around local sunrise, when it is called "the Dawn Chorus." Often accompanying Earth's magnetic storm associated auroral displays and natural radio chorus is "hiss," "wavering-tones," and other endless varieties of natural radio sounds.

Just when lightning seemed a rather common and well studied phenomenon, awesome as it is, Mother Nature throws another "wow!" at mankind. It seems we can now add the terms "red sprites" and "blue blobs" to our lightning storm vernacular. I am fascinated by recent videotaped evidence presented to the world scientific community and also general public pertaining to massive red and blue bursts of lights occurring as high as 20 to 30 miles above lightning storms.

For years, pilots of high-altitude aircraft were reporting sightings of strange blue and red lights seen above lightning storm clouds which were occurring at the same time as lightning flashes in the clouds below. In the summer of 1994, scientists from the University of Alaska Geophysical Institute in Fairbanks, Alaska were at last able to very clearly videotape these incredible lights using high-speed video cameras located on the ground and aboard two aircraft flying over storms in the U.S. Midwest. As though squirted out of a spray bottle, bursts of red light can be seen bursting upward in a stream right over lightning strokes and flourishing in a great cloud of light, lasting for about 1/10th of a second.

Fascinating as these baffling red and blue lights are, what's even more intriguing to natural radio listeners like myself is a quote from one of the researchers, David Sentman of the U. of Alaska Geophysical Institute, who says that the radio signals, when played through an audio speaker "sound like eggs hitting a griddle." Sounds like the hundreds of thousands of "crackling" sferics I have heard and tape recorded through the years, many of them (but certainly not all or most) have set off nice whistlers. I have always pondered at the sheer LENGTH of many of these lighting sferic crackles--quite a few of them are about a second in duration, and there are occasionally crackles which carry on for almost 2 seconds! These times seem far longer than any actual flashes of lightning I've ever witnessed, although it would seem lightning strokes can trigger other lightning strokes (via these immense radio energy impulses), seemingly supporting the reasons for such lengthy sferic "crackles."

Now, it would seem I've been hearing the radio sounds of sprites and blobs - I wonder if re-naming my WR-3 "Whistler Receiver" to a "Sprite & Blob Receiver" might be appropriate. Seriously, there is thought amongst whistler listeners that these weird lightning strike emissions are what may be causing whistlers, since they offer visible evidence of a linkage of energy from above the lightning storm clouds toward the ionosphere. They do not occur during every lightning stroke, just like whistlers do not happen after every lightning stroke. Since the Aurora Borealis and Australis (more commonly referred to as the Northern and Southern Lights) also generate fantastic VLF radio sounds, it remains a dream of mine to video-tape the Northern Lights while simultaneously recording their radio emissions onto the audio sound track.

I have watched aurora in Canada dance in the skies and listened to their beautiful whistling and squawking in the whistler receiver--bursts in intense aurora would also create bursts of auroral radio sounds. I understand the U. of Alaska Geophysical Institute in Fairbanks (the same folks studying the "Red Sprites" and "Blue Blobs" over lightning storms) has created an extremely sensitive (equivalent to 2 million ISO) video camera. They videotaped beautiful auroral displays in the Alaskan nighttime skies with astounding high clarity and detail, something never before achieved. Most auroral photography requires time-exposures with still cameras to turn out brightly. But then, the fine detail of the auroral curtains becomes smeared due to the motion of the auroral displays.

The most basic receiver required to pick-up and record whistlers and all of the other Natural Radio signals of Earth is a tape- recorder audio amplifier connected to a wire antenna (aerial) of sufficient length to transfer enough radio energy into the tape- recorder's audio amplifier to successfully record them.

In actual practice, however, this crude tape-recorder/audio- amplifier "receiver" will most likely also intercept your local broadcast station transmitting in the long or medium-wave band as well as other signals, and it may not have enough "sensitivity" since tape-recorder inputs rarely are well "matched" in impedance for wire aerials but prefer microphones and such. Fortunately, whistler receivers are not too complicated to construct--or today--purchase. A handful of parts and a couple of specialized transistors can form the basis of a very good whistler receiver that will perform very satisfactorily and almost as well as the professional study units that cost upwards of several hundred dollars.

In closing, I invite readers to join in and listen to the wonderful radio sounds of Mother Earth. You needn't be interested in science or be a radio buff, but need only to have the desire to lend an ear to the extraordinary yet ordinary. Like star gazing, Natural Radio listening redirects the mind and heart toward the wonder and beauty of the natural world.

Stephen. P. McGreevy, January 1995, updated and converted in entirety to HTML with photos December 1996. Additional revisions 10 October 1997

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Robert A. Helliwell ("Father" of VLF research), *Whistlers and Related Ionospheric Phenomena*, Stanford University Press, (1965).

Natural VLF Radio Sound Descriptions:

Naturally-occurring VLF Radio sounds descriptions:

Note: The text of this document was written for my CD-set "Electric Enigma." You will read several references pertaining to thie CD, however, the information usefully describes what you will hear live with a VLF receiver designed for 0.1 - 15 kHz reception.

Lightning-stroke "static": If you've already listened to ANY of these recordings, you will have certainly noticed (or may even be fed-up with) the nearly constant crackling and popping noises on each and every one of these CD's tracks. An unavoidable part of Natural VLF Radio, lightning static is ALWAYS audible, though, depending on the location and time of year, the amount of lightning static can widely vary.

Generally, recordings made in local summer are plagued with lightning- storm static and those made in mid-winter tend to be wonderfully quiet. While a nuisance to some listeners, VLF lightning static is trying to tell us something. Imagine a bolt of lightning--say-a bolt of lightning that strikes the ground from a cloud above. The length of this awesome spark can be many miles long and as wide as an automobile.

Between 10,000 to over 100,000 volts are generated in this instantaneous jolt. Furthermore, a single lightning bolt rarely fires just once, but as much as 100 times a second, giving it that odd "flickering" effect. As such; each and every one of those innocent "pops" evident in these recordings is one of those huge sparks just described. But as you may have already observed, there are seemingly HUNDREDS of them per second occurring in many of the recordings, some of them really loud, but most quite moderate to faint. They seem to permeate the background--sort of like an old, worn vinyl record.

Obviously, there is A LOT of lightning going on "out there!" And there are-a couple million lightning strokes (flashes) occur each day, worldwide, from approximately 1500-2000 lightning storms in progress at any given time. A VLF receiver is quite good at picking up lightning from as far as 3000 miles distant (perhaps more), and gives you a nice idea of the SHEER amount of lightning strokes firing off in any given second! You may experience days or weeks of sunny, delightful weather where you live, but the VLF receiver NEVER lets you forget that lightning is lurking all 'round you!

Tweeks: You might have already noticed a lot of the lightning static ("sferics") seems to have odd pinging and ringing characteristics. This "tweeking" effect, sometimes quite beautiful sounding (such as in the Fish Rock Road Whistlers track), is generally a nighttime effect, with a few tweeks audible in the late afternoon/early evening and reaching their best and most numerous around midnight, and finally tapering off once sunrise occurs.

At about 50-55 miles in altitude (80-88 km), the E-layer of Earth's ionosphere (a layer of charged particles, called "ions") acts similar to a mirror to VLF radio waves. The same goes for Earth's surface (more- or-less) and the two "sides" form a sort of pipeline which channel VLF radio signals, especially lightning stroke static impulses. Static impulses from very distant lightning storms (thousands of miles) can travel better at night in this huge radio wave pipeline of Earth, but, below a certain frequency, there is an abrupt cut-off, whereby the pipeline effect ceases. This is at about 1700 Hz audio frequency, which is also the frequency which most of the ringing and pinging sounds of tweeks are taking place.

Tweeks slowed down about 10 times almost begin to mimic low-pitched whistlers! Like Whistlers, one can get lost in the explanation of what causes a Tweek, and so it's sometimes more fun just to enjoy their odd sounds. Also like Whistlers, Tweeks can sound very different from night-to-night, sometimes very pure and ringy, other nights they have a "crusty" sound. During those (frequent) times no other Natural Radio sound can be heard besides incessant static, listening to Tweeks themselves can be mesmerizing!!

Whistlers: Most people get introduced to Natural Radio by hearing a recording of a whistler. Indeed, whistlers are the most common Natural VLF Radio sound besides lightning static, especially for those listening in middle latitudes. The term "Whistler" broadly defines downward- falling sounds which range from nearly pure whistling tones to windy/breathy sounds more similar to a "sigh" than a whistle. Between these extremes are a vast variety of whistler types.

In the case of the whistlers recorded in the eastern Nevada high desert, I called those whistlers "growlers," since they sounded more like growls than whistles. Of course, there are many samples of whistlers in these CD's. Whistlers are the direct result of a lightning stroke firing off, and usually occur 1-2 seconds after an initiating lightning flash. Very few of any lightning strokes ever produce whistlers, but enough do to make things very interesting on the good days, and sometimes whistlers are so numerous as to be called "Whistler Showers" or even "Whistler Storms."

Earth's magnetic-field, which keeps compasses nicely pointing in one direction only (hopefully!), plays a major role in the formation of whistlers. Not fully understood to this day, the traditional theory assumes that SOME of the radio energy from SOME of the lightning strokes in just the RIGHT location get "ducted" into channels formed along the lines of Earth's magnetic field, traveling out into near space and to the opposite hemisphere, where they are heard as a short, fast whistler (explained in more detail in the accompanying booklet with this CD set).

If conditions are favourable, some of the energy from these short, fast whistlers rebounds back the way it came to "arrive near" (within several thousand miles of) the point of its initiating lightning stroke, and becoming magically louder and longer. Essentially, during its globe-hopping round trip, the "all-frequencies-at-once" radio signal of a lightning "pop" gets the privilege of being pulled and stretched apart, with its higher audio frequencies arriving sooner than its lower frequencies, hence the downward-falling tone.

Some, if not MOST days are DEAD--entirely devoid of the sounds of whistlers, but there can be those days where whistlers rain down too many to count, like a huge switch was thrown by somebody "up there." Listen to the recordings, and you get the idea...

Chorus: Another general term used to define a number of Natural VLF Radio sounds, chorus defines several types of sounds when they occur in a rapid, intermixed form. The individual squawks, whoops, barks, and chirps of "triggered emissions" tend to get lumped into the general term of "chorus" when they occur in large amounts together. Depending on the time of day, location of event (or at least where it was heard), Chorus becomes "Auroral Chorus" (it was occurring near auroral sources or during visual displays of aurora), or around the pre to post-sunrise period, when it is called Dawn Chorus." Both sound generally similar, though chorus can manifest itself in endless variety.

Chorus is a product of magnetic storms, when events on the Sun, such as a solar flare, or "holes" on the Sun's outer atmosphere (the Corona) allow a barrage of high-speed charged particles to impact Earth's outer magnetic field (magnetosphere), causing it to deform and pulsate, much like air currents deform the thin film of a soap bubble. Phenomena such as Aurora (Northern and Southern Lights) also increase dramatically during magnetic storm periods, as do such natural VLF Radio sounds such as chorus.

Notice the similarities of the various Chorus events presented on these two CD's, yet also notice the variations. Short- lived repeating bursts of the individual sound components of chorus are sometimes referred to as "Chorus Trains." Auroral Chorus tends to be heard more often and at generally higher latitudes than whistlers, except for the widespread Dawn Chorus, which, when heard at lower-middle latitudes, is strictly a magnetic-storm time phenomena.

Hiss: Also called "Hissband," is a VLF radio emission partially arising directly from Aurora, with some of it emitted right from the same location as where the visible light (usually greenish in cast) is produced and usually very high-pitched.

Other hissband is generated farther out in Earth's magnetosphere including the bow-shock region of the magnetosphere facing the incoming Solar Wind. Hiss can vary in its frequency band, sometimes it has a high-pitched sound like a slightly open water valve or toilet-tank filling up, and on other occasions can sound much like the low-pitched roar of a waterfall. While generally stable in characteristic, it can sometimes abruptly change in volume and/or pitch, indicating some sudden change has occurred in the geo-magnetic field.

Periodic Emissions: Other sounds different than whistlers or chorus get lumped into this category, but is the term implies, they tend to occur only occasionally (periodically) and in repetitious fashion with a predictable repetition time (period). They often occurr in the whistler-mode and can echo back and forth. More frequently heard at high geo-magnetic latitudes, such as in Canada and Alaska, Scandinavia, or Antarctica.

Tonal Bands: Strange-sounding hissy noises, or a multitude of whistling sounds which abruptly begin and end, usually for only 5-10 seconds in duration. Many of these can be heard in the "Alberta Auroral Chorus" track (CD1, Track 9 and CD2, Track 1), particularly the longer recording.

Man-made VLF emissions:

Omega: All of the recordings presented on these 2 CD's have, to a greater or lesser extent, a high-pitched "beeping" sound toward the high-frequency end of audibility.

These are the sounds of the worldwide Omega Radionavigation System. Omega--now inactive as of 30 September 1997 thanks to the advanced GPS (Global Positioning System) satellite navigation system. RUSSIAN ALPHA system still remains and cab stillbe heard. The USGC Omega consisted of eight 10,000 watt transmitters in the following locations: Australia (Victoria), Japan; Hawaii (Oahu); North Dakota (USA); Liberia (Africa); La Reunion Island; Argentina; and Norway. Each transmitter transmited eight "pulses" of 0.8 to 1.2 seconds duration, repeating the process every 10 seconds. During each cycle, each transmitter occupied a unique frequency, and over the course of each 10 second cycle, all of the eight transmitters "hit" on several common frequencies spanning 10.2 to 13.8 kHz.

Also, each transmitter transmitted on its own "unique" frequency on 2 of its 8 transmitted pulses. Omega receivers used to sample the relative phase and timing of each Omega signal. Best results were obtained when at least 4 Omega transmitters were received and analyzed, and the nearest resolution, called a "lane," is about 5-6 miles (8-10 km), though in critical regions, supplemental transmitters of very low power may be used in order to increase navigation accuracy. Omega was subject to the same VLF propagation disturbances which affect Natural Radio, particularly during magnetic storms. When Dawn and Auroral Chorus roar, Omega is probably experiencing accuracy problems!

There were also daily (diurnal) variations in the accuracy and phase of the Omega signals as day becomes night, which for the most part were taken into account within an Omega receiver's internal microprocessor. GPS does not suffer any of these propagation errors as does Omega.

As such, Omega is no longer on the air, though Russia still operates a smaller-scale version of Omega called "Alpha." Alpha has only three transmitters sending three short pulses of approx. 100 milli-second duration followed by a pauseof a couple seconds' duration. Alpha is much weaker in strength than Omega, particularly for listeners previously within a couple thousand kilometres of an Omega transmitter.

Power line "hum" from alternating current electric wires: Switch on a VLF receiver within your home or office, and you will not hear anything BUT this sound! Today, all electricity generated at power plants is "alternating-current (AC)," as opposed to "direct-current (DC)" produced from batteries in your watch and portable radios. With AC, the polarity changes a many times a second. In Europe, Asia, most of Africa, and Australia/New Zealand, the electric mains power changes polarity 50 cycles-per-second, or 50 Hz. In North America and in most Central and South American countries, it is at 60 Hz.

While convenient for long- distance transmission and easy voltage transformation, AC generates hum in poorly filtered audio equipment and especially in whistler receivers! If this wasn't bad enough, most electrical "grids" seem to cause the 50 of 60 Hz current to generate harmonics--multiples of 50 of 60 Hz, causing hum/buzz THROUGHOUT the VLF radio spectrum. Those immense, high-voltage, high-tension electric wires sagging between the tall metal pylons and marching off toward the horizon can generate impossible amounts of hum and buzz if you try to listen with a VLF receiver too close to them-and I'm talking about miles or kilometres near to them!

To have "hum-less" recordings of VLF phenomena (such as the Eve's River or Alaska Auroral Chorus or Kenai Crazy Whistler segments), you have to find listening sites far removed from above-ground power lines. It's fairly easy to find absolutely quiet hum-free listening spots in desert and mountainous or tundra regions of North America, Australia, or the remoter parts of Europe and the British Isles (Scottish Highlands particularly) if you're willing to make a few days of it, but finding quiet spots to listen close to home and/or in populated regions such as the English Midlands or U.S. east and midwest (including farmed areas away from towns) usually mean pesky power lines will be around somewhere, usually alongside the road you're traveling along.

Willingness to walk/hike into listening sites greatly increases your chances that a quiet spot will be found. In most cases, you have to live with SOME background hum, as must I. Thus, some of the recordings on these CD's or your potential favorite VLF listening sites have some weak background hum.

Surprisingly, reasonably quiet natural VLF radio listening spots can be found in places such as large ball fields, large urban/suburban parks away from light poles, farm fields where wires are hidden behind trees, along many beaches (especially if electric wires are below-ground), and so forth. It has been found that within southwest London's Richmond Park and Battersea Park, quite a few remarkably low-hum listening spots exist. This is also true for San Francisco's Golden Gate Park's soccer/football playing fields. Certainly, other big-city parks must also have low-hum VLF listening spots you could listen with your VLF receiver!

Stephen P. McGreevy, March 1996, revised October 1997

POCKET-PORTABLE WR-3 & WR-3E NATURAL VLF PHENOMENA RECEIVER LISTENING GUIDE

Text-only version - please see http://www.triax.com/vlfradio/wr3gde.htm for full version with images

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Welcome to the realm of extreme and very-low-frequency (ELF/VLF) "Natural Radio!" The WR-3 and the Deluxe/Enhanced WR-3E are both an electric-field ("E-field") type of "whistler receiver" specifically designed to monitor naturally-occurring VLF radio emissions of Earth **that occur in the 100-11,000 cycles-per-second (0.1-11 kHz) audio-frequency ELF/VLF radio spectrum**. Both receivers employ a short 33-inch/84 cm telescoping whip antenna (included) and require stereo-mini headphones.

The original WR-3, in production since September 1991, and the newer design (1993) Enhanced WR-3E has become one of the more popular VLF receivers to date due to its pocket portability, ease-of-operation, and high-sensitivity with a short antenna. It is the end-result of a third prototype version of a handheld VLF receiver developed by Frank Cathell and Steve McGreevy of Conversion Research in August 1991.

The original WR-3 and the (enhanced) WR-3E (which has an improved LC bandpass filter and also a high-pass filter plus microphone-level output RCA jack for tape recording) are now produced and distributed by S. P. McGreevy Productions as of November 1993. These two receivers are currently in use in about 30 countries worldwide by individual listeners and research groups. For the remainder of this Listening Guide text, both receivers will be referred to as "WR-3/3E."

Earth-along with several other planets in the Solar System including Venus, Jupiter, Saturn, Uranus and Neptune - produces a variety of naturally occurring radio emissions at the lowest end of the radio spectrum (< 10 kHz), primarily in the form of electromagnetic (radio) impulses generated by ongoing lightning storms and also from the Sun's solar wind interacting with the magnetic envelope surrounding Earth, called the "magnetosphere." A large variety of unusual and beautiful Natural Radio sounds can be heard at ELF/VLF frequencies. These naturally-occurring radio signals are the subjects of ongoing scientific research by both amateur and professional groups, and are being monitored both on the ground by users of the WR-3/3E, other ground-based VLF receiver systems, and by unmanned space probes and satellites.

It is at these lowest frequencies of the radio spectrum in which no man-made signals are assigned, that planet Earth's own mysterious radio emissions have been happening for eons. These fascinating "sounds" are "primal radio"-indifferent to the affairs of humankind-and insight into the causes of these ancient phenomena has only begun to be unraveled in the past 50 years, particularly commencing with the International Geophysical Year beginning in 1957.

LIGHTNING-STORM ATMOSPHERICS ("SFERICS") & TWEEKS: NOT JUST MERE "STATIC"

Besides 50 or 60 Hertz (and harmonics) alternating-current powerline "hum" from electric-utility power grids, the most noticeable sounds are going to be the snap, crackle and pop of lightning-stroke electromagnetic impulses (called "atmospherics" or "sferics" for short) from lightning storms within a couple thousand miles of the receiver-the more powerful the lightning stroke or the closer it is to the WR-3/3E VLF Receiver's location, the louder the pops and crashes of sferics will sound in the headphones. Several million lightning strokes occur daily from an estimated 2000 storms worldwide, and the Earth is struck 100 times a second by lightning. The WR-3/3E makes quite an effective "lightning monitor"-at times the receiver's output is a cacophony of crackling and popping sferics in an ever-changing texture from lightning strokes originating in storms near and far.

These huge sparks of lightning strokes, whether from cloud to ground or within a lightning cloud cell, are tremendously powerful sources of electromagnetic (radio) emissions throughout the radio-frequency spectrum-from the very lowest of radio frequencies up to the microwave frequency ranges and the visible light spectrum. However, most of the emitted electromagnetic energy from lightning is in the very lowest part of the radio spectrum, from 0.110 kHz, which are the frequencies the WR-3/3E VLF receiver has been designed to monitor. The powerful electromagnetic radio pulses produced by lightning strokes travel enormous distances at these very-low radio frequencies, following the surface of the Earth as "groundwaves." It is quite interesting to note how generally quiet and lightning sferic free the hours are from just after sunrise to midmorning, when thunderstorms tend to be at their minimum. Later, the crackling and popping of lightning sferic activity picks up as afternoon thunderstorms build in numbers and intensity because of thermal heating and convection, especially in the summer and autumn months, when, by sunset, the sferics (snap, crackles and pops) are roaring in a varied and ever-changing texture as lightning storms rage on into the evening. Weather monitoring agencies employ special receivers that receive and direction find lightning sferics in order to determine where lightning strikes are occurring and the potential for wildfire ignition, hazards to aviation, and damage to electric power utilities from those lightning strikes.

While to some, the popping and crackling of lightning sferics may sound like just annoying "static," you should keep in mind that each click or pop is a lightning stroke flashing somewhere, and you also should note just how MUCH lightning is going on even though your local weather may be cloudless. Additionally, distinct seasonal variations in the density of moderate to strong lightning sferics are very noticeable with the WR-3/3E. During the winter months in the mid-latitudes, when the electrical storm density is generally at its lowest, the amount of strong sferics are also at a minimum. Mid-winter, especially in the higher latitudes north of 40 degrees, can be very quiet with very little lightning sferic activity. However, a weak but continuous background level of lightning sferics may be audible between the few strong sferics-these are from the higher amounts of lightning storms occurring in the tropics and from the opposite hemisphere's summer lightning storms. Contrast that to local summer evenings, when there is a continuous "roar" of lightning sferics heard with the WR-3/3E. The Earth is truly "awash" with lightning storm activity! Aesthetically, the random nature of lightning stroke sounds in the headphones can be soothing, much like the patter of rain drops on a roof.

At night, many of the popping and crackling sounds of sferics take on a pinging/dripping sound, called "tweeks," and can be quite musical sounding. Recordings of tweeks slowed down about 8 times sound vaguely like "Chinese Opera" gongs. Tweeks are a result of the impulse path from the lightning stroke to the receiver being influenced by the Earth surface-to-ionosphere (D and E-layers) region, which is about 4575 miles (7320 Km.) in height, measured vertically during the nighttime hours. This region between the lower ionosphere and surface of the Earth acts as a "duct" or "waveguide" at these VLF radio frequencies, which have wavelengths ranging from 18 miles/29 km. at 10 kHz to over 186 miles/289 km. @ 1 kHz, allowing lightning stroke impulse energy to travel considerably farther than during the daytime. As the lightning stroke radio energy travels and is reflected within this Earth-ionosphere waveguide, the energy undergoes a slight "dispersion" effect whereby the higher frequencies of the lightning impulse arrive slightly before the lower ones within a fraction of a second. The waveguide dispersion effect abruptly cuts off below about 1.5 to 2 kHz (1,500 to 2,000 Hz) in frequency, resulting in the ringing/pinging "tweek" sound which is also centered around 1.5-2 kHz. This ringing/pinging "tweek" sound you hear is the lowest resonance frequency of the ionosphere-Earth surface waveguide. This is similar effect to what sound waves experience in a pipeline. If you have ever clapped your hands inside a pipeline that was between 1 to 3 feet in diameter, you will notice a sound somewhat similar to the radio sound of tweeks. Because the Earth surface to ionosphere waveguide cannot support radio energy below about 1.5 kHz, the dispersion effect is cutoff below that frequency, thus creating the resonance-like pinging and ringing sound.

The sounds of tweeks can change on an hourly basis and from night to night, with the ringing and pinging effect very intense and musical at times, especially in the middle of the night in summer and autumn when there is a higher density of relatively strong sferics. Only a few pops and crackles of sferics may be "tweeking," or all of them can be, and the tweeks may sound "crusty" or be very clean pings and rings. Tweeks can be indicators of the condition and height of the lower layers of the ionosphere to researchers, but to many listeners to them, they also contribute to the aesthetic sound of Natural Radio.

SAFELY DISTANT (over 30 mi./45 km away) but visible summer-time "heat-lightning" can make for a fascinating study of the nature of the electromagnetic sferics and their correlation with the visible characteristics of the lightning. The sounds of sferics from ground strikes compared to the sound of sferics from cloud-to-cloud/within cloud lightning strikes can be observed, and which of those lightning strikes are triggering whistlers, if they are at all. Exercise caution when viewing distant lightning and be prepared to discontinue use of the WR-3/3E and seek safe shelter if lightning clouds approach your listening location.

The WR-3/3E can also be employed as a lightning detector, albeit a crude one, by detaching the telescoping whip antenna whereby the antenna screw post becomes the receiver's "antenna." Any invisible lightning strokes in suspect cloud formations will emit strong enough impulse sferics (pops/cracks) which will be audible in the WR-3/3E's headphones. By de-sensitizing the receiver in this fashion, it will receive only lightning sferics that are very strong and hence emitted from close-by lightning. This should be done only in a safe location and not out in the open where any nearby lightning might strike. If out in the open and very strong lightning sferics are heard with suspected lightning clouds nearby, immediate lightning safety precautions should be instituted immediately. Never take shelter under trees during lightning-the induced ground currents from a nearby lightning strike to trees can kill!

WHISTLERS - Endless varieties...

In addition to the musical pinging, dripping, popping and crashing sounds of lightning sferics and tweeks, you may be rewarded by hearing downward falling musical notes ranging from nearly pure to "swishy" or "breathy" sounding tones from 1/2 to over 4 seconds in duration. These are the aforementioned "whistlers," and they may sometimes happen a couple of seconds after some of the static crashes and pops of sferics from lightning strokes. One of the best known natural radio phenomena, Whistlers generally sweep downward in frequency from about 6 kHz to around 0.5 kHz, but the lower cutoff frequency does vary markedly as conditions change, and the upper frequency of whistlers can sometimes start higher than 10 kHz. Whistlers sound quite fascinating-sort of like some "science-fiction" sound effects-and besides lightning sferic "static" are one of the more common Natural Radio sounds you can hear with your WR-3/3E. They occur in many varieties and characteristics.

The Earth's outer magnetic field (the "magnetosphere") envelopes the Earth in an elongated doughnut shape with its "hole" at the north and south magnetic poles. The magnetosphere is compressed on the side facing the Sun and trails into a comet-like "tail" on the side away from the Sun because of the "Solar Wind," which consists of energy and particles (plasma) emitted from the Sun and "blown" toward Earth and the other planets via the Solar Wind. Earth's magnetosphere catches harmful electrically charged particles and cosmic rays from the Sun and protects life on Earth's surface from this lethal radiation. Among the charged particles caught in the magnetosphere are ions (electrically charged particles), which collect and align along the magnetic field "lines" stretching between the north and south magnetic poles.

These magnetic-field aligned ions bombarding Earth's magnetosphere form "ducts" which can channel lightning-stroke electromagnetic impulse energy. Whistlers result when an electromagnetic impulse (sferic) from a lightning-stroke enters into one of these ion-ducts formed along the magnetic lines of force, and is arced out into space and then to the far-end of the magnetoionic duct channel in the opposite hemisphere (called the opposite "magnetic conjugate"), where it is heard as a quick falling/descending emission of pure note tone or maybe as a brief "swish" sound. Whistlers sound the way they do because the higher frequencies of the lightning-stroke radio energy travel faster in the duct and thus arrive before the lower frequencies in a process researchers call "dispersion." A person listening with a VLF receiver like the WR-3/3E in the opposite hemisphere to the lightning stroke (at the far end of the Magnetospheric duct path) will hear this "1-hop" falling note whistler. One-hop whistlers are generally about 1/3 1 second in duration.

If the energy of the initial "1-hop" whistler gets reflected back into the magneto-ionic duct to return near the point of the originating lightning impulse, a listener there with a VLF receiver will hear a "pop" from the lighting stroke impulse, then roughly 1 to 2 seconds later, the falling note sound of a whistler, now called a "2-hop" whistler. two-hop whistlers are generally about 14 seconds in duration depending on the distance the whistler energy has traveled within the magnetosphere. One-hop whistlers are usually higher pitched than 2-hop whistlers.

The energy of the originating lightning stroke may make several "hops" back and forth between the northern and southern hemispheres during its travel along the Earth's magnetic field lines-of-force in the magnetosphere. Researchers of whistlers have also observed that the magnetosphere seems to amplify and sustain the initial lightning impulse energy, enabling such "multi-hop" whistlers to occur, creating long "echo trains" in the receiver output which sound spectacular! Each echo is proportionally longer and slower in its downward sweeping pitch and is also progressively weaker. Conditions in the magnetosphere must be favorable for multi-hop whistler echoes to be heard. Using special receiving equipment and spectrographs, whistler researchers have documented over 100 echoes from particularly strong whistlers - imagine how much distance the energy from the 100th echo has traveled - certainly millions of miles/Km! Generally, only 1 to 2 echoes are heard if they are occurring, but under exceptional conditions, several echoes will blend into a collage of slowly descending notes and can even merge into coherent tones on a single frequency, hard to describe here, but quite unlike any familiar sounds usually heard outside of a science-fiction movie!

It should be reiterated that strong 2-hop (and echoes) can occur from lightning that is not necessarily close to the listener or even within a couple of hundred miles from the your listening location, but perhaps from lightning that is over 1000 miles distant. You may notice that "louder" sferics (i.e. closer lightning strokes) often do not trigger the loudest whistlers, if they do so at all, but then a loud whistler may come howling through from a relatively weak sferic from quite distant lightning. This is because the lightning impulse sferic energy may propagate within the earth-ionosphere region for considerable distance before entering a magnetospheric "duct." A vast majority of fine whistlers are heard during periods of locally fair weather-lightning need not be within visible distance. In fact, many extremely loud "big whistlers" are heard WITHOUT ANY preceding lightning sferic audible whatsoever, indicating the initiating lightning-strokes of those strong whistlers are very far away-possibly over 3000 miles!

Whistlers are best heard in latitudes between 30 and 60 degrees north latitude in North America, with the prime latitude being 30-50 degrees north. (More on this under the "WHERE TO LISTEN" section further on).

At higher latitudes such as in Canada, Alaska or Scandinavia , an type of whistler - called "nose whistlers" can be easily heard. These are named for the way they appear in spectrograms, and often occur in clusters. They are quite spectacular sounding. Nose whistlers have both rising and falling frequency components. Compare the nose whistler spectrogram below to the one of the whistlers recorded in Nevada above.

Every whistler is triggered by a lightning stroke, and lightning that is DISTANT enough away not to pose a danger to the listener with the WR-3/3E but which is also **visible** (especially at night) can sometimes trigger whistlers (very weak to very loud) shortly following the simultaneous visible flash and loud radio static "pop"/"crack" of the local lightning sferic in the WR-3/3E receiver's headphones. If the whistlers you hear coming from the visible lightning strikes are very loud, this indicates a magnetospheric duct happens to terminate relatively close to your location. Because the sferics from lightning strokes within 50 miles to your listening location will sound EXTREMELY LOUD in the headphones, keep the audio gain setting **low**.

Don't confuse the sounds of tweeks with the longer duration whistlers, which many newcomers to Natural Radio monitoring tend to do at first. Tweeks, as explained above, have a similar sound to water dripping into a bucket of water, are of roughly the same duration as a "drip," and generally are accompanied with the "click" or "pop" sound of the lightning stroke impulse. Whistlers on the other hand are much longer in duration than a tweek-from 1/2 second to as long as 4 seconds in duration.

MAGNETIC STORMS, AURORA, & THE BEAUTIFUL SOUNDS OF "CHORUS"

Occasionally, shortly after sunrise and occasionally extending into the midmorning, a phenomenon called "Dawn Chorus" may occur. Dawn chorus can resemble the sound of a flock of birds singing and squawking, dogs barking, or sound like whistlers raining down seemingly by the hundreds-per-minute (called a "whistler storm"). Dawn Chorus generally results from hundreds of overlapping, rapidly upward rising tones that can be continuous or appear in bursts, called "chorus trains." These chorus trains sound very fascinating-the bursts of chirps and squawks (risers) seem to suddenly commence, and over the course of 2-5 seconds, weaken and fade away, then repeat over again, often in different pitches. During a chorus train, the sounds sometimes seem to be echoing or reverberating back and forth until fewer and fewer risers happen, then there may be a brief pause before the next chorus train commences. Chorus trains also seem to be harmonically related-a chorus train's center audio frequency may alternate randomly, first centered on about 1 kHz, then another chorus train will suddenly start up one octave higher at around 2 kHz, or maybe 4 kHz. Bursts of chorus trains happening at different octaves can overlap in a truly beautiful sounding cacophony.

Dawn chorus can occur several times a month for listeners in middle latitudes during years of high sunspot activity (1989-1993) after solar flares and/or coronal mass ejections on the Sun send a barrage of charged particles into the Earth's magnetic field, causing a geomagnetic storm and also producing Aurora (the Northern and Southern Lights). In years of low-sunspot counts and few solar flares (1994-1997), coronal mass ejections from the Sun can still cause magnetic storms once or twice a month.

Chorus doesn't always only occur at dawn, especially for listeners who are located at higher latitudes, particularly in southern and central Canada (50-55 degrees north latitude), Alaska, and in northern Europe. At these higher latitudes closer to the auroral zone, which is a ring (oval) surrounding the magnetic pole and usually passing through central Alaska and through Canada at about 57-62 degrees north latitude, as well as northern Europe (Iceland, northern Scotland & the Hebrides Islands, Scandinavia, etc.). The auroral zone is source to a vast amount of natural VLF phenomena. When a solar disturbance on the Sun (such as the aforementioned solar flare or coronal hole mass ejection) sends highly charged and high-speed particles and ions towards Earth via the Solar Wind, Auroral displays often occur, and are visible to people near the auroral zone oval. Earth's magnetic field also undergoes a "storming" process as well, called a "magnetic storm." During auroral displays, chorus is often heard, as well as "hiss" of various pitches, "sliding-tone emissions" which very eerily and weirdly rise in pitch slowly over one to several seconds' duration. The chorus which occurs during displays of Aurora is called "Auroral Chorus."

As such, both Auroral chorus and dawn chorus are related in that they occur during magnetic storms. The more severe the magnetic storm, the farther south away from the auroral zone and the louder the chorus will be heard with the WR-3/3E. It is known that the Auroral Zone "oval" surrounding the magnetic poles expands during magnetic storms and reaches farther southward (and the southern Auroral Zone "oval" in the southern hemisphere expands farther northward). It has also been discovered that aurora is a daytime phenomenon but is not visible to the naked eye due to daylight illumination of the sky. Particularly intense events of nighttime and dawn chorus can get very loud even for listeners below 40 degrees north latitude (in the U.S.), and point to the evidence that aurora can reach considerably southward into the middle latitudes despite it not being visible.

The maximum intensity region of chorus emissions, like aurora, can spread southward during magnetically disturbed periods. Daytime aurora can sometimes be more intense than nighttime Aurora, and events of auroral and dawn chorus can reveal quite an array of information about the nature of aurora.

Nighttime auroral hiss (in at least a weak form) can be heard well over half the nights a year for listeners in Alaska and central and northern Canada along with a plethora of other phenomena, particularly during active auroral displays around 10 p.m. to 2 a.m. local time. And these same locations good for auroral viewing will also often experience wonderful dawn and daytime chorus which will carry-on the entire day, peaking around noon local time and gradually tapering off in the late afternoon. Good chorus events are sometimes accompanied by whistlers that have an extraordinary amount of "echoing"-10 or more echoes may be noted on some whistlers and the echoes may blend into a coherent tone or band of "hiss" which seems to be very slowly descending in pitch. Other sounds such as "wavering-tone" or "whispering wind" sounds may also be heard in addition to the phenomena described above.

If you can see Aurora (Northern or Southern Lights) or the news media is mentioning them, by all means listen for possibly interesting and unusual whistler and/or hiss activity, which is likely occurring along with the auroral displays - with great Chorus events to follow the following morning and into the day - as is common at higher latitudes.

Even if geo-magnetic conditions seem "quiet" and no chorus events seem likely, conditions may still be very good for whistlers to occur-determining when whistlers are going to happen is still a rather unpredictable affair. More on this topic in the following sections...

GEO-MAGNETIC STORM, AURORAL & SOLAR ACTIVITY REPORTS

Geomagnetic storms (which result from solar flares and particularly coronal-hole mass ejections, causing Aurora and VLF radio Chorus as described earlier) are announced on short-wave time-standard stations WWV in Colorado and WWVH in Kauai, Hawaii at 18 minutes past each hour on WWV and 45 minutes past each hour on WWVH. Both stations can be heard on 2.5, 5, 10, 15 MHz. WWV additionally is on 20 MHz. During these "geo-alert" notices, the A and K-indices are announced. These indicate the amount of magnetic disturbance K of 0-1 = quiet, K of 2-3 = unsettled, K of 3-4 = minor storm, K of 5-6 minor-major storm, K above 6 = major-severe geo-magnetic storm. If the K-index is above 3, the A-index above 25, and they are saying the geomagnetic field is at "active," "minor storm" or "major storm" levels, odds are that some form of natural emission is likely to be occurring besides the ubiquitous sferics and tweeks.

Dawn chorus may also occur on mornings that seem to be having only "active" or "unsettled" geo-magnetic field conditions (K-indices from 2-3) according to WWV/WWVH, so don't rule out times when the magnetic field is not "storming" according to WWV/WWVH, since it MAY be storming at very high latitudes and producing fine chorus emissions. Also, regarding whistlers, they can be howling by the dozens-per-minute even though the A & K-indices are seemingly "bottomed out" (say, A = 7 and K = 0 or 1 which indicate "quiet" geo-magnetic conditions), so the geo-magnetic indices give less clear of an indication that whistlers may occur than of potential dawn chorus or auroral chorus events.

Whistlers DO seem to be more common around the equinoxes of March 21 and September 21. As an alternative to the WWV and WWVH geo-alerts at 18 or 45 minutes past each hour, a couple of computer bulletin boards (BBS's) exist which supply detailed information on solar activity and related phenomena. One of these BBS's, the "Solar-Terrestrial Dispatch" (based in Stirling, Alberta, Canada) has aurora and magnetic storm announcements, as well as weekly and monthly reports of past activity, weekly predictions of future magnetic conditions, and Aurora reports sent in by observers. The Solar-Terrestrial Dispatch BBS can be reached at (403) 756-3008. Its parameters are 300-2400 baud, 8, N, 1, full-duplex (echo-on). There is currently no charge for basic services (besides long-distance phone charges), but subscribers (for a small fee) get much more services as well as access to special reports and software related to solar and geo-magnetic observations. Alternatively, use their fantastic Internet World-Wide Web site at this URL: **http://solar.uleth.ca/solar/www/hourly.html**.

The other popular BBS and Internet site is based at the Space Environment Services office in Boulder, Colorado, U.S.A., and supports 2400 baud, 8,N,1 parameters (the same as the Solar Terrestrial Dispatch BBS mentioned above). The phone number for this free BBS (you must register your name and address though) is (303) 497-5000. You can obtain a considerable amount of information pertaining to Geo-magnetic and weather related phenomena. Better yet, they also have a gopher URL: **gopher://proton.sec.noaa.gov**. This site's text-only menu system can be viewed with any Web browser, is fairly easy to navigate and has loads of information albeit possibly too technical in nature for many newcomers to natural VLF radio listening and "space weather" studies. There are also URL's given to get to additional text and graphical information via the Web.

Another fine NOAA-based web site is: **http://www.ngdc.noaa.gov/stp/stp.htm** This is the Solar-Terrestrial Physics Division Home Page Finally, in addition to the NOAA and Canadian STD sites is the IPS Space and Radio Services out of Australia. They maintainn another fabulous web site at: **http://www.ips.oz.au/** - IPS Australia Home Page (Solar-Terrestrial Research)

WHEN TO LISTEN FOR NATURAL RADIO PHENOMENA AND WHERE IN THE WORLD THEY OCCUR:

Statistically, the time between local midnight and an hour after sunrise is when the greatest amounts of whistlers are heard, although dusk to midnight may reveal substantial whistler activity, and even (though not very often) loud whistlers may be heard a couple of hours before sunset. Over the long term, the period from two hours before sunrise until an hour after sunrise is the optimum time to listen for natural VLF phenomena of all sorts, as the amount of sferics (lightning stroke pops and crackling) are less - natural VLF radio phenomena are not as "buried" under the sferics as in the evening when lightning storms are more numerous. Also, magnetospheric conditions are optimum around morning twilight time.

Interestingly, between April 1996 and March 1997, I have been hearing good whistler events during the DAYTIME and particularly late afternoon before sunset! Many times these whistler events die out after sunset. In early march 1997, whistlers started up around 4 p.m.local time and were going in earnest (several-per-minute) between 8 p.m. and 11 p.m. PST. This may be a solar-minimum phenomenon, but it points out the need to listen as much as one can for whistlersand at ANY time, as they occur when least expected. This recent late-afternoon trend has not always been the usual case a few years ago and many listeners got used to listening only near sunrise. Therefore, whenever I am out hiking in areas even just a bit away from powerlines, I bring along my WR-3E! (S .P. McGreevy)

While the pre-sunrise hours are generally the best time to listen for whistlers and other phenomena, intense whistler events of short duration can occur at any time between just before local sunset through 1 to 2 hours after sunrise. A good whistler event that is happening at 10 p.m. or even at SUNSET may not be occurring later on that night at the usually optimal sunrise period, so don't rule out the evening hours to listen, especially during geo-magnetic storms.

On several mornings a month, one whistler a minute may be heard on average, but as is often the case, whistlers will not be heard at all. Occasionally during a geomagnetic storm caused by a solar flare, over 100 whistlers a minute or more may be heard - called a "whistler storm!" Whistlers may or may not have echoes and they may be few and far between and very loud, or may occur often but be quite weak. The sound characteristics, intensity, and number of whistlers can change rapidly hour to hour. Everything depends upon the sensitivity and conditions of Earth's magnetosphere and the location of lightning storms and magnetospheric ducts in relation to the WR-3/3E VLF Receiver user.

Whistlers are seldom heard midday, except during unusual conditions occurring with a geo-magnetic storm or unusually strong electron and proton output from the Sun impinging upon Earth's magnetosphere. Unfortunately, on a good number of days during the year there will not be any whistlers audible even though there is plenty of lightning activity and sferics within a few hundred miles of a listening location. Often elusive, whistlers may not be heard for days or weeks at a time. Again, it is hard to predict when whistlers are going to occur based on the geo-magnetic indices, but they are generally more common in the spring and the fall, surrounding the equinoxes and at sunrise, or more rarely, at sunset.

In North America, latitudes where the Northern Lights (Aurora Borealis) are visible are excellent locations to hear whistlers, loud Auroral and Dawn chorus, and a myriad of other Natural Radio emissions when they are occurring. For instance, in the center of the Canadian Provinces of Alberta through Ontario, chorus of infinite variety is an almost daily occurrence, even when geo-magnetic indices would seem to indicate listening would otherwise be "dead" farther south! Spend a week or two in August, say, in central Alberta and/or Manitoba, Canada (as I did in 1996) or in central Alaska, and you too would be delighted and in awe of the Natural Radio sounds heard each day...

For Europe, similar fabulous chorus listening locations would be northern Norway and Finland; Iceland, and the northernmost parts of the British Isles.

For middle-latitude listeners, Dawn Chorus (as previously mentioned) tends to peak in intensity between sunrise and one hour afterward, but at high latitudes, can peak as late as noon or even in the mid-afternoon, particularly if there is any geo-magnetic activity (Kp index > 2) and can take on incredibly beautiful sounds.

Whistlers of intense strength can be heard across the middle and southern-most United States and southern Europe and North Africa. The latitudinal zone where the loudest whistlers are heard falls roughly between 30-55 degrees north for North American listeners. In the United States, statistically, the "northern tier states" region is blessed with the highest number of whistlers and chorus occurrences (Washington State, northern Idaho, Montana, North Dakota, Minnesota, Wisconsin, Michigan, Pennsylvania, New York, and New England. In Canada, the southern parts of British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec and the Atlantic

Maritime Provinces hear large amounts of whistlers and chorus. Throughout central Canada and Alaska, wonderfully strong chorus events lasting from morning to evening can occur, particularly in Feb. April and August - early October.

Strong events of chorus occurring at higher latitudes can be heard into more southern latitudes too, albeit somewhat weaker and less often. Everywhere, the lightning impulse "static" sounds of sferics and tweeks from Earth's great number of electrical storms abound. Elsewhere, southern Canada, all of Europe, especially northern Europe and the British Isles, are good locations to listen for both whistlers and chorus.

In the Southern Hemisphere, New Zealand, the Australian states of Tasmania, Victoria, South Australia and parts of Antarctica are also prime whistler monitoring regions, as would be locations along a radius of about 3,000 mi./4800 km. radius around the southern magnetic pole. Note that both the north and south magnetic poles don't fall on the true geographic poles of the Earth but are several hundred miles offset. The geographic coordinates of the north magnetic pole is approx. 75 degrees north latitude by 100 degrees west longitude. The south magnetic pole is approx. 67 degrees south latitude by 155 degrees east longitude. Whistlers have been reported in Saudi Arabia despite its southern geographic latitude. In rare cases and very strong whistler events, whistlers can be heard even at the Equator.

Whistlers have also been observed by unmanned spacecraft passing by the planets Jupiter and Saturn which also have considerable electrical storm activity and very powerful magnetospheres.

In summary, the zone where the loudest chorus events occur is higher in latitude than whistlers (please refer to the maps), and for North American listeners it is between 45-60 degrees north latitude. In some locations, such as northern British Columbia or in Alaska, the whistler rate is slightly lower than in places such as Washington state, Minnesota or Maine, but Chorus will occur far more often in Alaska and in central Canada than farther south.

Also, since we're just now beginning a new solar cycle (# 23 - due to peak around 2000-01), increased sunspot/solar-activity will mean the regions of good Chorus and whistler events will start to move southward again. Places experiencing few Chorus events will begin to hear more of it - and louder too. In a few years, locations such as central California, Colorado, Virginia in the U.S.; the central Europe; southern Australia and Africa will hear chorus and other events which were, at the bottom of the solar-cycle in 1996, heard only closer to the magnetic poles such as in Canada.

You shouldn't be discouraged if after several listening sessions, whistlers, chorus, or other VLF phenomena sounds (besides lightning sferics "static") are not immediately heard. Sooner or later, you will be rewarded with a variety of fascinating sounds from whatever VLF phenomena is occurring at the time you listen-as though the times of not hearing anything are suddenly "made up for" by a listening session filled with all types of beautiful VLF radio sounds! As a reminder, weather and outside temperature permitting, the period around local sunrise will be the most rewarding time to listen. Natural VLF Radio signals can sound truly eerie and awe-inspiring, especially when one realizes it is all naturally occurring - not man made, and that these radio emissions have been occurring for millennia.

SUGGESTIONS ON FINDING A GOOD PLACE TO LISTEN:

The WR-3/3E VLF receiver should be operated well away-at the very least 1/8 to 1/4 mile (300-600 metres)-from any 50/60 Hz A.C. powerlines or structures that contain them, such as houses and buildings, or else a "hum" sound from the A.C. powerline frequency (and harmonics to well above 1 kHz) will dominate the WR-3/3E receiver's output. This is because the alternating current frequency of 60 Hz (50 Hz outside of North America, Hawaii, and most of South America) carried by power lines also puts out harmonic emissions every multiple of 50 or 60 Hz, and these power-line harmonics can be easily received by the WR-3/3E. Locating a listening spot 1/2 to 1 mile (800-1600 meters) away from power lines if possible will probably eliminate most if not all "hum" interference. The farther away you can locate away from electric power lines, the less "hum" will cover the desired VLF Natural Radio phenomena, especially the weaker and more subtle ones.

Lower voltage underground power lines such as those within newer residential neighborhoods may not be an annoyance at 1/4 mile/1000 meters away from them, however, high-tension/high-voltage power lines in "utility corridors" can cause some hum even 2 to 3 mi./3 to 5 km distant in worst case situations. Powerline buzz and hum presents the greatest obstacle to Natural Radio listening for most listeners, and more-or-less eliminates "backyard" listening, thus requiring some sort of "expedition" to an electrically quiet location, which can often be quite challenging but fun! The WR-3/3E is a great receiver to take with you on wilderness trips, whether via car, boat or on foot.

It's also important to be in a clear, open place away from trees by at least 50 yards/meters - a meadow, field, or open hilltop is best. Trees act as electrical-field "short circuits" at these low frequencies - the WR-3/3E VLF Receiver will lose sensitivity as you get closer to trees and other obstacles. All VLF signals will be attenuated almost completely if the WR-3/3E is operated under trees, no matter how few of them are around. Standing under a lone tree surrounded by miles of open space will be little better than being deep in the woods - relocate away from trees and be in the open. In short, AC power lines cause annoying "hum" that masks all other signals and trees reduce all the signals there are to hear, so it is best to locate a listening site away from both of them. You need not seek the highest location around to listen with the WR-3/3E, but if you listen in deep valleys and canyons, signals will also be reduced somewhat.

When using the WR-3/3E VLF Receiver, hold the whip antenna as vertically as possible while grasping the aluminum enclosure, whereby your body will act as a "ground." Additional grounding can be accomplished by clip lead attached to one of the screws on the aluminum enclosure of the WR-3/3E and to a 6-8 inch nail, stiff wire, or rod stuck into the soil where you use the WR-3/3E, but this will not be necessary unless you tape record the output of the WR-

3/3E or wish to eliminate capacitive "foot" noise caused when shoes are rubbed on the ground or when dry grass or shrubs touch your clothing or shoes.

CAUTION: DO NOTLISTEN TO VLF WHEN NEARBY LIGHTNING STORMS THREATEN AND TAKE APPROPRIATE LIGHTNING PRECAUTIONS! Most of the time, better whistlers will be heard when their sources of lightning are not close to your listening location anyway (and as far away as 2,000 miles or more due to the complexity of whistler radio wave paths). The lightning static will be too loud for comfort anyway. Many listeners have the mistaken impression that they will only hear whistlers when lightning is close-by, but this is not the case for the most part. When lightning flashes nearby, put away your WR-3/3E and wait until the storm passes.

OTHER INTERESTING EFFECTS: INSECT WING SOUNDS

A very interesting electrical effect easily observed with the WR-3/3E are insect wing sounds caused when insects such as bees, flies, and mosquitoes fly within a couple of feet of the WR-3/3E whip antenna. The resulting sound is a buzzing sound very similar to what can be heard by ear, however, this effect is caused by electrostatic discharges each time the insect's wings flap. It is thought that electrostatic charges (static electricity) are collected on the insect's wings and then and dumped during each wing beat, creating a "modulated" electrical field around the insect at the same frequency as the wings beat. Large insects, such as wasps, Yellowjackets, Bumblebees and honeybees, make particularly strong buzzing sounds in the WR-3/3E headphones-easily heard when those insect fly within 3-4 feet (1 meter) of the WR-3/3E antenna. High-pitched Mosquito wing beat sounds can be heard the small insects fly within a few inches of the WR-3/3E Receiver's whip antenna.

Certain kinds of flies and other insects have much more electrostatic "buzz" from them than other kinds - Bees and Horse Flies, in our observations, have the loudest "buzz" in the headphones! This may also have something to do with the composition of the insect's wing, with certain type of insect wings more prone to static electricity accumulation and subsequent discharge. There may also be insect bodily electrical discharges generated within the insect's wing muscles that contribute to this effect, but not much is understood about this phenomenon.

Enjoy your WR-3/3E and the sounds of VLF "Natural Radio." Listening to the sounds of whistlers, tweeks, chorus, and other Natural Radio sounds under a star filled sky or while watching aurora or sunsets and sunrises increase one's wonder and appreciation of the natural beauty of Earth-the WR-3/3E is simply a tool to enhance sensory awareness of Earth's natural beauty further, and into another "realm," whether for research purposes or aesthetic enjoyment. Awareness of WHY these sounds happen and their origin, much of it gained through scientific study and learning, helps to satisfy our curiosity about them. The necessity of taking the WR-3/3E out of the electrically "polluted" urbanized areas and into more open areas further into nature adds to the enjoyment and appreciation of the natural environment. Happy Listening!

Additional References and recommended reading for those interested in additional information about natural VLF phenomena:

Michael Mideke, *Sferics: A Beginners Guide to Whistlers, Tweeks, and Other Natural Radio Sounds and How to Hear Them*, Whole Earth Review, pp. 96100, Fall 1990. With illustrations. Highly recommended reading. The complete issue might be obtained by writing to the publisher, Whole Earth Review, P.O. Box 38, Sausalito, California 94965, and by enclosing $7.00 for the indicated issue, though it might not be available from them any longer. Alternatively, try your local public library.

The Lowdown, published by the Longwave Club of America (LWCA), is a monthly publication for people interested in this part of the radio spectrum. In addition to articles on Natural Radio sounds including writings by Mike Mideke, the publication covers lowpower Low and Medium Frequency experimental transmitting of voice and data, receiving techniques, radio wave propagation, and articles about controversial topics such as military radio transmissions, etc. Membership is $18.00 per year ($26.00 U.S. Overseas) from: LWCA, 45 Wildflower Road, Levittown, PA 19057.

Ionospheric Radio Propagation, by Kenneth Davies, National Bureau of Standards, Monograph 80 (1965/1990). Excellent text on radio propagation including verylowfrequencies. The old 1965 edition is nearly impossible to find but a new 1990 edition (priced at about $65.00) is available. Write to: Space Environment Services Center, NOAA R/E/SE2, 325 Broadway, Boulder, CO 80303-3328. Phone (303) 4975127.

Robert A. Helliwell ("Father" of VLF research), *Whistlers and Related Ionospheric Phenomena*, Stanford University Press, 1965. A very comprehensive introduction to whistler research before space flight plus the beginnings of "spaceage" research documenting early satellite data. It is accurate and concise with numerous diagrams and illustrations. The book has more information than a beginner would likely immediately use or pursue, but is fascinating nonetheless. ***RARE BOOK*** It is difficult to find copies of this book. Check large libraries. They may be able to obtain the book using the interlibrary loan system.

Syun-Ichi-Akasofu, *The Dynamic Aurora*, Scientific American, May 1989, pp. 90-94. Describes the functioning and structure of the magnetosphere and causative factors in the generation of Aurora. Examines the magnetosphere as an electrical "generator," field-aligned currents, electrojets and substorms, why Aurora are "curtain" shaped. While not directly examining VLF natural emissions, the article helps in understanding the magnetosphere and lends insight into its role in naturally occurring VLF emissions.

Jeremy Bloxham and David Gubbins, *The Evolution of the Earth's Magnetic Field*, Scientific American, December 1989, pp. 68-75. Examines geologic processes which generate Earth's magnetic field, describes the shape and functioning of the geo-magnetic field, magnetic field drift, magnetic lines-of-force, magnetic field polarity shifts, and so on.

George John Drobnock, *Radio Waves from a Meteor?*, Sky & Telescope, March 1992, pp. 329-330. Reports on the author's experiences with a homemade H-field "loop" VLF receiver and a noted "hiccup in the background noise" as well as a "swoosh" sound correlating with the sighting of a meteor on two separate occasions. Examines the possibility that large meteors may disrupt the magnetic field because of their ionized "wakes" created by swift passages into the upper atmosphere, causing VLF radio emissions. An under-researched and still-controversial premise demanding further attention.

Russ Sampson, *Fire in the Sky*, Astromony, March 1992, pp. 38-43. Beautifully illustrated article about the phenomenon of Aurora and the geo-physical processes responsible. Written more for the layman than the Syun-Ichi-Akasofu article above, but essentially covers the same topics including the influence of solar activity on the magnetosphere. The article is replete with excellent amateur photographs of various colors of aurora. Since Natural Radio emissions arise from the same processes, this is also recommended reading to gain understanding about the magnetosphere.

Donald Herzog (U.S. Geological Survey, Golden, Colarado), *Hazards of Geomagnetic Storms, Earthquakes & Volcanoes*, Fall 1991

David Schneider (Assistant Professor of Physics, Northern Kentucky University), *Mother Nature's Radio*, QST, January 1994, pp. 49-51. Discusses basic theory about VLF whistlers and the VLF frequencies of 0.1-10 kHz, Earth's magnetosphere, whistler VLF experiments, whistler sonograms, whistler recording and analysis setup, basic definition of Natural Radio terms, and how to get involved in whistler monitoring and research.

Tom Kneitel (editor of Popular Communications Magazine), *Radio's Incredible Rock Bottom!*, Popular Communications, September, 1992, pp.9-13. Introductory article on the amazing variety of "Earth Sounds" to be heard in radio's "Basement Band."

Don't Blame Solar Flares, Sky & Telescope, June 1994, page 12 (News Notes). Explains how sceintists have been mistakenly explaining solar flares as the causes of geo-magnetic storms rather than coronal mass ejections (CME's), which now appear to be the cause of many, if not most geo-magnetic storms. A CME injests plasma into the solar wind as speeds of 2,000 km/sec., often faster than the solar wind, causing a shock front which impacts Earth's magnetic field, triggering magnetic disturbances (and aurora along with natural radio emissions). With 4 photographs showing an expanding CME of 18 Aug. 1980, 1004-1310 UT. Syun-Ichi Akasofu, The Shape of the Solar Corona, Sky & Telescope, November 1994, pp. 24-27. Modern astronomical research has found the Sun's corona (outer atmosphere) to have the same structure throughout a Solar Cycle (from solar minimum to solar maximum), and that the apparent visual shape variances during a solar cycle are caused by polarity reversals of Sun's magnetic field during a solar cycle. Conventional solar photography has created the "myth" that the Sun's corona is uniform at solar maximum and non-uniform at solar minimum, due to over exposure of photographic film. (The sun's magnetic field can interact with Earth's in ways which enhance or suppress geo-magnetic storms and their accompanying auroral displays and natural ELF/VLF radio "chorus" emissions).

Neil Davis, *The Aurora Watchers Handbook*, University of Alaska Press, 1992 Fantastic book and a must for those interested in observing auroral displays visible in the far northern tier of the U.S. "Lower 48" states, Canada, or Alaska. Chapeters include: Cause of the Aurora, basic facts and definitions, such as the auroral zone, auroral forms, etc., kinds of auroras, variations in the aurora, control of the aurora by Earth's magbnetic field, aurorally-related phenomena (such as auroral sound/VLF radio, folklore and legends about aurora and auroral mysteries. I used this book and it was a VERY useful guide during my 2-week Manotoba VLF recording and auroral-viewing expedition to central Manitoba, Canada in August 1996.

QUICK TIPS FOR MAXIMUM ENJOYMENT OF YOUR NATURAL VLF PHENOMENA RECEIVER

This is a summary of what you can do to maximize your enjoyment of your WR-3/3E VLF Receiver (or other VLF receivers) and your success at hearing Earth's VLF radio emissions:

Listen for Natural VLF Radio sounds in locations as far as possible from above-ground electric utility power lines (A.C. power-lines). A minimum distance of ¼ - ½ mile (400-800 meters) away from power-lines is recommended. This is because the alternating-current frequency is 50/60 Hz (cycles-per-second or "Hertz") and this frequency is within the WR-3/3E's receive frequency range. Plus, there are "harmonics" in the power-line frequencies well past 2-3 kilo-Hertz (kHz), often resulting in an annoying mix of "humming and buzzing" which masks Natural Radio sounds if you are too close to power lines. Good locations for you to listen might be large school playing fields away from nearby electric power lines, farmlands, large parks, empty lots not surrounded by buildings and power-lines, golf courses, etc.

If you have access to open-space areas such as meadows, hilltops, beaches, etc., that's all the better! If you can listen at remote locations such as rangelands, deserts, hills or mountains many miles from electric lines, you may not hear ANY background "hum," and thus, you'll hear even the most subtle Natural Radio phenomena. And, just being in a beautiful and remote location will enhance your enjoyment and awe at Natural Radio phenomena-it IS a part of Nature. NOTE: Motor Vehicles with their engines OFF usually do not create interference to Natural Radio.

Second to listening to Natural Radio away from electric power-lines is to locate yourself away from nearby obstructions such as trees and large bushes as these tend to dampen the "E-field" that the WR-3/3E is sensitive to. The WR-3/3E will be essentially useless even if you try to listen while next to or under even ONE tree even though that tree may be located in an otherwise open area. Locate meadows and fields if possible, in locations which have many trees. Listening at "high ground" locations is better than listening in deep valleys, gorges, and canyons, as the VLF "E-field" is also reduced by being near steep terrain if it is above you.

Listen at sunrise if possible, as the vast majority of times you will hear Natural Radio sounds, especially whistlers and "The Dawn Chorus" will be at dawn and shortly after. 2 hours before sunrise up to 9 a.m. local time is the best. If you like the ringing/pinging sounds of "Tweeks" and the popping and crashing sounds of lightning "Sferics," you may want to listen just after local sunset up to midnight, when Tweeks are at their best. Whistlers may also happen beginning late afternoon and peak in activity between 8 p.m. and midnight your local time, particularly in late winter and early spring.

The ferocious sounds of lightning-storm "Sferics" are also best in the evening hours of the Summer and Fall when lightning storms are at their greatest number and intensity, though the amount of whistlers and chorus will generally be far less than on towards sunrise.

If you have limited time to listen and want the greatest chances to hear interesting Natural VLF Radio Sounds, 5-7 a.m. local time would be the best period to do your listening sessions. The period of day when you are generally LEAST likely to hear any Natural Radio sounds other than the popping and crackling of lightning storms is between 11 a.m. to 2 p.m. local time. However, midday activity DOES occur, especially at higher latitudes, and these events should be considered extraordinary. We urge you to avoid listening when lightning is nearby (within 5 miles/8 Km) as you run the risk of being struck by lightning if out in the open with your WR-3/3E (The receiver doesn't attract lightning, but your body CAN, just like trees and other objects).

Resist the temptation to listen when lightning is nearby as the impulses in the headphones will be VERY loud. Watching lightning flash while listening to the static impulses with the WR-3/3E can be exciting, but S. P. McGREEVY PRODUCTIONS can not be held responsible for injury or death due to misuse of equipment or by being struck by lightning.

If you have a World Band (Shortwave Radio), listen to WWV Colorado, USA on 2.5, 5, 10, 15 & 20 MHz at 18 minutes past the hour (or WWVH Kauai, Hawaii on 2.5, 5, 10 & 15 MHz at 45 min. past the hour) for "Geo-Alert" indices-if they say the "K-index" is at 3 or higher, conditions are enhanced for Natural VLF phenomena to occur. If the K-index is 4 or higher, and they say there is a "minor geo-magnetic storm" or "major geo-magnetic storm" in progress or forecasted for the next 24 hours, by all means listen the following morning at dawn for eerie and beautiful "Dawn Chorus," which is likely to occur.

If you live far enough north to see the Northern Lights (Aurora), try to listen when they are happening or on toward sunrise after nights of good displays-you will very definitely hear some intriguing VLF radio sounds off of the Aurora such as Auroral Chorus! Geo-magnetic storms cause Aurora, and reported WWV/WWVH K-indices of 4 or higher greatly increase your chances of seeing Auroral Lights and hearing Auroral Chorus or Dawn Chorus with the WR-3/3E. Northern listeners will probably hear chorus last past local noon during magnetic-storm periods. Surprisingly, active auroral displays at night may not produce much VLF radio sounds other than "hiss," but loud chorus surely will start up before local dawn and sunrise, and go on many hours into daylight with exciting variety. Strange sounding whistlers with sustained echoing may also occur.

Miscellaneous VLF related correspondence with others, FAQ's etc.

In HTML and plain-text starting below

1) File of various discussions about whistlers and why they don't follow exact conjugate paths - I. E. why loud whistlers are often heard from very weak and distant lightning.

plus - OMEGA SHUTDOWN REPORT - 30 September 1997

October 1997 S. P. McGreevy - Lone Pine, CA

---begin copy:

I spent the past 2 days (and some 6 days in late Sept.) at my friend's place relaxing after hard and heavy work days at home between those time-outs. Up there, I always listen to VLF during the night and whistler activity is really up compared to august. Static is down to decent levels again too.

Omega shut down! Here's a copy of my report to a few other people:

Well, I got a nice recording of Omega's last beeps and also two nights of nice whistlers too, especially this morning, 01 October, between 1100-1330 UT. There was also some intermittant dawn chorus starting at about 1230 UT and going until after 1500 UT - I had not yet caught chorus this summer or fall until now, so I was really glad to hear some chorus even though it was not very strong, and overall a really nice 2 days of whistler listening. Many whistlers this morning (October 01) had echoes too! The whistlers seemed to be generated by fairly nearby lightning - not too local but within 1000 miles.

I have found that indeed (and this is shown in a more recent book on magnetospheric physics), whistlers don't follow exact paths and congugate points AT ALL(!!!). Often, loud whistlers at any locale may be generated by lightning somewhat far away (1000-2000 miles perhaps) while more closeby lightning is NOT generating the loudest whistlers (which may be loud 1000 miles away somewhere ELSE!) Listening since mid-august has given me quite a bit of observation in this regard and countless examples on tape. I mentioned this somewhat subjectively in my VLF STORY I wrote a few years back and I'm even more sure of this. Sooo, Mexican or Montanan lightning may make LOUD California whistlers, and at the same time California lightning may make for loud whistlers in Colorado or even Kansas (to use a scenario). Certainly, there are times when nearby lightning does make for the loudest whistlers, but this is more infrequent in my observations than the scenario above.

Anyway back to Omega's shutdown--I started recording at 0257 UT 9/30. I made a WWV time check at 0259 on the tape and then let it run with the WR-4b whistler receiver set to high-pass--lots of Omega into the tape recorder. At about 0259:30, Omega D (North Dakota) shut down, leaving Omega-C Hawaii going for about 4 more of its cycles. About 0300 (or within a few seconds) and after its first of two 11.8 kHz beeps, Omega C went off. Both D and C did not shut off abruptly, but did a sort of 'fade-out' over a 1-2 second period. Interestingly, going over the tape in slow motion revealed a third Omega station running on until a minute or so later - the 10.2 kHz beep was noticed. Probably H-Japan, the next strongest station here in CA usually. By 0301 UT, all that was left was the Russian Alpha system - short beeps in clusters of three beeps, a pause, then three beeps again in downward frequency steps. Russian Alpha is much weaker and higher up in frequency (up to 14.1 khz) then Omega was and has a far lower duty-cycle, and so the natural radio band is really MUCH cleaner sounding suddenly! It's also fun to observe Alpha propagation - I guess the strongest one I get is from Siberia--it is stronger toward sunrise than at any other time of the day by 3-6 dB or so.

There are supposedly three(?) stations in the Alpha chain. Do any of you three fellows know of info on the Russian Alpha system - locations, frequencies and format? Certainly, Alpha is going to continue for a while and it is going to be noticed by some listeners even though it is fairly weak. I'd like to put Alpha information into the VLF Listening Guide replacing the Omega info. ---end copy

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To Ed Hendricks:

I mentioned in prior e-mailings to you both my "theory" that (2-hop) whistlers don't follow exact and predictable paths based solely on the basic Heliwell magneto-ionic theory, but they can take differing paths and wind up being heard loudly considerably far from their sources of lightning. I just added this part to my VLF STORY at:

http://www.triax.com/vlfradio/vlfstory.htm/#kimura

Here is a copy of a notable paragraph from an AGU article I came across a while back after purchasing three large books from the AGU late last year (sorry about the screwy line breaks):

---BEGIN COPY:--- (Author's note: Long after I wrote this piece and surmised from my many years of listening to VLF and observing whistlers that magnetic field conjugate points were not really fixed on two given points in Earth's opposite hemispheres, such as Marion island and southern England, I came across an intriguing scientific paper in the American Geophysical Union's Geophysical Monograph 53, page 161, entitled "Ray Path's of Electromagnetic Waves in the Earth and in Planetary Magnetospheres." This copyright 1989 paper written by Iwane Kimura of the Dept. of Electrical Engineering II, Kyoto, Japan, presents many graphs, mathematical formulae and diagrams of bi-polar magnetic field models of Earth showing wave-path tracings of man-made VLF signals transmitted from Siple Station in Antarctica and received by orbiting satellites. One particular paragraph written by in this article summarizes up nicely the potential for a great variability of whistler paths and conjugate points:

For ray tracing of whistler mode waves in the earth magnetosphere, the simplest model of the geomagnetic field is a dipole model. Most of the ray tracing techniques treating wave phenomena in the earth magnetosphere have been based on the dipole model. Actually, however, *real geomagnetic field lines are known to be fairly deformed from dipole field lines, so that for whistler waves, whose propagation are strongly governed by the geomagnetic field direction, ray paths calculated using the dipole model will differ considerably from those in the actual magnetosphere. (I. Kimura - Kyoto Japan, 1989)*

--END---

Anyway, that is yet another firmer bit of evidence that we're NOT always (or even all that frequently) hear whistlers anywhere NEAR its source lightning, and it explains why we sometimes hear such strong whistlers from seemingly weak sferics (or none audible at all!

In an e-mail to Tracey Gardner - England:

Speaking of lightning proximity, many people are under the mistaken impression that there has to be lightning in the area (if not nearby) to hear whistlers. But, whistler propagation paths are complex and often, loud whistlers heard at any given location may be from lightning as much as a couple thousands miles away. More recent data from research has revealed that the actual magnetic field is very different in shape, and field lines can vary *markedly* from the 'perfect' dipolar model of the geo-magnetic field.

In my VLF STORY article on my web site (http://www.triax.com/vlfradio/vlfstory.htm) I added a reference to Iwane Kimura and two paragraphs that rather nicely summarises that aspect of (wildly varying) whistler paths.

More E-mail correspondence and FAQ's

(E-mail addesses removed out of respect for the privacy of the person I wrote back to - this keeps them from getting spam-mail)

```
Subject:
            Re: VLF radio in TN
       Date:
            Sat, 20 Mar 1999 14:57:04 -0800
       From:
            "Stephen P. McGreevy"
Organization:
            S.P. McGreevy Productions
         To:
            "George R. Vaughn (in Tenessee)

Hi George,

I wanted to answer these questions - sorry for the bit of delay - I know
you're
```

expecting an answer soon and glad to help!

Before I get into the questions, we're in a slack period (March 18 - 20(but expect the
great activity and associated solar activity and Coronal mass ejections to come about
again, as the sun rotates on a roughly 27-28 day period, April 3rd and a bit later
ought to be a swell period of days to be out listening - all night to morning - chorus
is there is a mag storm again like early March. Right now in late winter 1999, we have
mag. storms happening about 3 times a month, with a big one once a month, and the
equicnoctal periods around march/april and again late august - early october are prime
times of the year for magnetic storms and other events due to a closer link up of the
earth and sun's mag. field.

>
> As a beginner in VLF below 10 KHz, I would like to ask you some questions:
>
> 1. What is my magnetic conjugate point? I live in Jackson, TN - coordinates
> are: Lat 35.6167 Lon 88.8133

Not really sure - I don't have any program that figures that out. In anycase, magnetic
conjugate points do drift markedly in the short term during magnetic storms and over the
long term (years) due to drifting of the magnetic poles. To get a rough idea of your
mag. conjugate, youhave to look at a map that has geomagnetic longitude and latitude
superimposed on a world map - I have one published back in the late 50's (i.e. not
excatly accurate to today but close enough) in the Heliwell book (formost IGY researcher
into whistlers) and the general conjugate point for TN is about 1500 miles west of
Tierro del Fuego in the south pacific - not known for its high activity of lightning
storms, but occasioanlly, you, as I, can hear a swarm of single-hop whistlers coming
from the south pacific lightning storms. Most whistlers I hear originalt inNorth
america, called two-hop whistlers - sometimes the lightning click or pop preceeds the
whistler, indicating two-hop. On good nights especially during mag. storms, there may
be multi-hop echoes on the whistlers.

I don't know where a current map showing the magnetic longitude and latitude are - I am
just an advanced hobbyist in this, not a real paid expert :].

>
> 2. Is it possible to hear whistlers in the daytime when the "D" layer of the
> ionosphere is present? I have noticed that tweeks are not heard until after
> sunset.

Yes, especially during magnetic storms and when the lightning is fairly close (within a
few hundred miles - 500 miles - closer than during the prime whistler periods after
dark. I heard some daytime whistlers during feb 18 - 19, 1999 mag storm at 1 p.m. near
Owens Lake, CA - from lightning pops that sounded within a few hundred miles. Overall,
whistlers are not common in the daytime at our mid-latitudes.

>
> 3. What times of the year do you listen? I have noticed your .WAV files have
> much less sferic noise than I am getting. Is this due to my location or am
> I listening at the wrong time? (Most of my listening is done at night; I
> am NOT an early morning person.)

All year, with peak activity mentioned earlier - in winter sferics usually are low, and
in summer as you surely know, the static in the afternoon and after sundown is horrible
- that is when I limit my listening to morning (sunrise and after). Static levels are
already much higher right now (MArch 1999) than two months ago, and overall, static
levels are lower out west (especially in the morning) than in the south-east US, except
when the west has monsoonal storms over the intermountain west, especially in AZ and
Utah in late august and in sept.

>
> 4. Is there a time of year when whistlers are more likely to occur? In the
> many years I have dealt with ionospherically-propagated signals, I have
> learned that almost anything can happen almost any time, but certain events
> are more frequent at given times of the year.

Yes - whistlers are hard to predict, but MArch and April, and August - early October
have proven to be the best whistler months in 8 years of listening I've done. I
also mentioned this above, too.

>

> 5. Where can I get a tape recorder that can operate from batteries and/or
an
>   automotive 12 V electrical system and would be suitable for recording
VLF
>   emissions. The Sony TC-100 I used for the Feb 3 recording has ALC as
does
>   virtually all portable cassette recorders. ALC is great for many
>   applications but reacts unfavorably to impulse noise.

Long's Electronics in Irondale, AL (mail-order firm) sells the Marantz PMD-
series of
pro-ccassette recorders that have been great for VLF enthusiasts and are
cheaper than a
DAT maching but BETTER than the Sono-mini-disc digital recorder., per
reports. I
have used a Marantz PMD-212 since October 1992 - all the recordings on my web
site
excpet for the Alberta June 1998 stereo recordings were made on my Marantz
machine. Get
the three-head unit so as to be able to monitor the actual recording being
laid down
on to the tape - this is critical - too much >10 kHz signals into the tape
recorder
result in what is known as "magnetic-tape intermodulation" - even if the
amplifier
output monitor seems clean! - this has been the key to my successful
recording over the
years..

>
> 6. Was there a solar event that affected the Earth's magnetosphere that
may
>   have resulted in the Feb 3 whistler "storm"? What about Feb 19... on
that
>   date I did a "no-no" - went out "VLFing" without a tape recorder and
heard
>   but had no way to record strong chorusing in the 4-8 KHz range.

Yea, two magnetic storms ocurred during those two periods - take a look at
this gopher
site (text for the most part and viewable with any web browser - look for the
'summaries; menu and check the data. This is the NOAA Space Environment Lab
site:

gopher://proton.sec.noaa.gov

I really find this site useful and fast loading! They teach you how to read
the
figures. The USAF predictions for the Ap index and solar flux are very
useful for
timing expeditions when you can go out and listen every day (I myself missed
all the
early March 1999 activity - too busy).

Hope this helps you George. Out of time for now--please pardon the typoes -
doing this
fast as I have a load of e-mail to answer--Good Listening!

Steve

--
Stephen P. McGreevy / S. P. McGREEVY PRODUCTIONS
Presenting Natural Radio Phenomena of Earth Below 10 kHz
*** Stereo Natural ELF-VLF Radio Recordist ***
http://www.triax.com/vlfradio --and-- http://dx.tc/vlf

Subject:
Re: VLF-IE listening crashes...?!
Date:
Mon, 19 Jan 1998 16:21:05 -0800
From:
"Stephen P. McGreevy"
Organization:
S. P. McGreevy Productions
To:
Gote.Flodqvist@*********.se
CC:
annika@(snip)
References:
1

Dear Gote,

I sincerely apologise for the very lengthy time to reply to your very interesting e-mail note recounting your disappointing VLF listening experiences up in northern Sweden during active auroral displays.

Perhaps I can explain my own experiences whilst VLF listening up near or in the auroral zone during expeditions from 1993 - 1996 to Canada.

During my Manitoba VLF expedition August 1996 to observe solar-minimum conditions, I frequently observed that during bright and intense auroral displays that covered most of the visible sky, there were hardly any VLF emissions heard other than weak hissband noises and perhaps strange sounding whistlers or very weak tonal sounds. Most of the spectacular VLF sounds were heard after local sunrise, particularly chorus -- correlating to heightened magnetic activity. This has lead me to believe (or confirm others observations) that strong aurora do not produce much VLF emissions, and that the majority of emissions of hissband and chorus are generated farther out in the magnetosphere in the bowshock region and then channeled in whistler-mode back to (or near) the listener's location.

>From many VLF listening trips toward the extreme southern reach of the auroral zone, it has becoms apparant that there are MORE VLF emissions during active auroral dislays seen far to the north than from locales WITHIN or UNDER the aurora! This may simply be more anecdotal and empirical evidence or assumptions, but it has been the situation on several VLF expeditions to be fairly certain. I can't explain why this is, but it is something that needs further study, and such study would be greatly aided by having several listening groups or individuals within and near (and perhaps well out of) the auroral zone to correlate and compare VLF events with auroral displays and the local magnetic

conditions.

Before I embarked upon the two trips made to central Alaska in September 1995 and west/central Manitoba in August 1996, I thought bright active auroral displays would spawn many VLF emissions, but this has not been the case at all, and your observations in northern Sweden within the auroral zone also verify my own observations. In al three situations, we were both quite dissappointed that we did not hear much interesting activity during the active visible auroral displays.

Indeed, we are learning more and more about the nature of VLF radio emissions and having some of our expectations challenged!

Thanks for your update, Gote! Please send me more information when you have it! Myself, I have been very busy with some other activities and have not been able to go out and listen to VLF much the past 2 months. I do plan on an expedition to Death Valley, California later this week.

Very best regards,

Stephen McGreevy

in reply to:

Subject:
VLF-IE listening crashes...?!
Date:
Fri, 17 Oct 97 14:03:14 +0200
From:
Gote.Flodqvist@
To:
vlfradio@
CC:
annika@m (snipped)

Hello Stephen!

Nice to hear from you. The headline is perhaps a somewhat dramatic, but the following story supports part of it.

SILENCE____
During a stay in northern Sweden from 23/9 to 28/9, I experienced two evenings with great auroral displays. And two evenings with a little less activity in the sky, but still a prominent aurora, from a southern living person´s view. Also, I was able to take some nice shots with my SLR-camera. One evening was cloudy (23/9), but according to a local magnetometer (IRF, Kiruna, http://www.irf.se/mag/) there were magnetic disturbances during the night.

I brought my VLF-IE equipment with me. It was used frequently to probe the condition of the ionosphere during daytime hours. At some sessions, I noticed a few weak, uninteresting whistlers. Also some low frequency noise was briefly present one morning. Well, no problem with that. Conditions do vary significantly and quiet conditions are of cause possible even at these high latitudes.

But, the first evening with northern light all over the sky, I very eagerly hooked up my VLF-JE gear to listen and ......and listen...and.. ...SILENCE! Nothing WHAT SO EVER.....only trivial tweeks and Omega-tones were present.
WHAT IS GOING ON UP HERE!? IT SHOULD BE CHOKED WITH SOUNDS!
I became most disturbed(="swedish") and disappointed. When this spectacular display was going on over head, it must be ANY sounds around correlated to the ionospheric behavior. But NOTHING! And this was the case during ALL the nights with aurora. I only heard, the last morning (28/9), a typical dawn chorus.

QUESTION____
My basic understanding is, that whenever there is an aurora visible in the sky, there are flowing currents around. These should in turn induce, in an electric conductor (such as our antennas), a voltage mirroring the original currents in the sky. The very one we want to listen to. This is the foundation upon we build our concept of VLF-IE-observations. But in this case the aurora produced nothing, nothing at all.

Could you enlightning me in this respect?

Down here, in Stockholm, I saw a weak aurora (+ Hale-Bopp!) and listen to fairly strong VLF-IE associated with it, once! I have not seen any other aurora and heard sounds correlated to it, so far. But anyhow, abound are other occations with spectacular sounds from above. And more is to come in the comming years when sunspots peaks. So I will certainly continue to listen.

LISTENING SITES____
When it comes to quiet listening places in Sweden, they are, generally speaking, available in the western mountainridges, by feet or by car if dirt roads permits.
If I should be specific I have used a few places:
Loevaanger (a small village, 64 deg, 20' N):
A few km down the road to the coast by a dirt track. Very low level of hum. Open landscape. Fast and easy access from the village and main (coastal) highway (E4) to northern Sweden.
Jukkasjaervi (a small village, 68 deg N, 20 km (32 miles) east of Kiruna):
A dirt road passing by a training stadium for moose(elk?)shooting. Entering a clear cut area after a few km. Excellent listening conditions. There are several useful dirt tracks in this area.

If you are prepared to trekk in these mountains, there are several nationalparks to walk in. Sylarna, Sarek, Kebnekaijse, just to mention a few. In these areas there are lodges and huts to sleep in, if you do not prefer to bring your own tent. All of them are excellent, silent places, except at a few spots near the park-entrances where a bigger lodge is placed, connected to the power grid thus creating a local noise.

Around Stockholm, the capital of Sweden, within a radius of say 50 km (80 miles), it is a main problem to find a true silent place. Acceptable sites are near the Baltic Sea, accessable via the main roads. Or boat. Or canoe.

We are now two people in Stockholm, who use the same basic equipment. A fishingrod, a FET-buffer, a freestyle-taperecorder. We listen, more or less on an everday basis, to the sounds of the sky! There is a prospect for a third person to join the VLF-IE listening party.

Best Regards
Göte
e-mail: Gote.Flodqvist@***.***.***.se

Subject:
Re: natural signals
Date:
Fri, 29 Jan 1999 11:55:55 -0800
From:
"Stephen P. McGreevy"
Organization:
S.P. McGreevy Productions
To:
EWER**@***.com
References:
1

Hi,

Oh yeah, that's Russian ALPHA transmissions - there is info on the TRAIX web site about that - check the URL below and look for the "Omega's Final minute" page - I put Alpha information there as well as in the WR_3/3E Listening Guide (lots of links to that document too).

Alphs is a radio-navigation system, quite obsolete, that is still being used over there. Omega, the Coast Guard system we had that had 8 transmitters worldwide, shut down 30 Sept. 1997

Yeah, you can escape the static sounds of lightning storms, those clicking, splatting sounds. In fact, the Researchers at the U. of Alaska Fairbanks, when studying those wierd sprites and jest coming out of intense lightning storm cells used the term "sounded like eggs hitting a griddle' to describe their sounds on a VLF radio, so your description is not quite appropriate! :]

best regards,

Steve McGreevy

EWER**@*****.com wrote:
>
> have you ever heard a faint high frequency signal in the 10khz or so range
> that is transmitted on and off in 1 plus second intervals? I'm up near the
> Hanford Nuclear Site and I've been hearing it off and on the last few weeks
> mostly during the morning hours between 8am and noon. The only other sounds in
> my locale seem to be similar to the pops and splatter sounds in some of your
> audio files plus a very short duration sound like an egg dropped in hot grease

> that goes on day and night around here. I don't actually know what they are
> caused by but I call them fry babies. Keep up the great work.

Subject:
question of quartz rocks
Date:
Thu, 14 Jan 1999 15:19:23 -0800
From:
"Stephen P. McGreevy"
Organization:
S.P. McGreevy Productions
To:
"Paul N. Boucher"
References:
1

Dear Paul,

I'm delighted that you and your daughter are enjoying the receiver and also already
doing some interesting experiments!

Back in August 1990 while on a trip to northern Nevada (Paradise Valley, north of
Winnemucca, NV), Gail and I noticed there were lots of quart rocks in the soil,
including some pretty large ones. Since I knew quartz has piezo-electroc properties,
and when compressed or stimulated, quartz generates electrical impulses, I tried exactly
the exeriment you have done. The loudest signal was most definitely from rubbing two
quartz rocks together, not quite so loud was just one quartz rock and a non-quartz rock,
and rubbing two other knids of rocks together had little of no audio in the receiver
headphones.

You're picking up the electrical waves generated by the quartz rocks upon being
stimulated - the signals are quite weak and are not only in the audio spectrum, but
actually broadband - if you place a regular AM broadcast radio (tuned to no station)
next to the quartz rocks, you will hear the same rubbing noises, sort of static-like.
There may be some sort of improved 'transmission' effect by the fact that you're holding
the quartz rocks - perhaps too, your bodies may inhibit the signal from the quartz due
to grounding, so maybe try rubber or cloth/wool gloves for insulation and see what

happens! More room for study and investigation here!

I believe that you're hearing a true radio signal, not an audio coupling effect. The
reason flying insects are heard also with an audio frequency radio receiver such as the
WR-3 is that the insect's wing-beat is in the audio frequency range, and 2) the insect's
wing material does either a) directly radiate a static impulse, like crinkling up a
piece of cellophane will also, or b) disrupt the static field surrounding the insect
(and everything else, hence a similar sound to what you hear directly with your ears
from the insects' wingbeats).

Late february through early April are peak whistler periods of the vernal equinox, so
the listening mught be good! I suspect this year will be the best since 1993 or 1994, as
we head back into another solar-cycle peak.

Thanks for the note, Paul - keep at it! Hope this helps!

Best regards and wishes in '99,

Steve McGreevy

Paul N. Boucher wrote:
>
> Dear Mr. McGreevy:
>
> My daughter and I have been enjoying the VLF radio you recently sent us (thanks for the fast response). We have been using it in conjunction with her science
>
> We have tried generating some sort of signal by rubbing and banging together quartz rocks (which are known to have electrical properties). We were able to rec
>
> We than tried the same with other "standard" rocks around our property. We got weaker, but similar results. We were even able to pick up "sounds" from rubbin
>
> The question is: Since we are generating sound waves by our activity in the same frequency range as the radio frequencies of the radio, could there be some so
>
> What do you think? Any suggestion as to how we can be certain it is a real radio signal?
>
> Thanks in advance -- we are thoughly enjoying the radio.
>
> Paul & Chantal Boucher
>

>   --
> Dear Mr. McGreevy:
>
> My daughter and I have been enjoying the VLF radio you recently sent
> us (thanks for the fast response). We have been using it in
> conjunction with her science project. We have encountered an unusual
> situation and would like your reaction and any advice/opinion you
> might have regarding our experience.
>
> We have tried generating some sort of signal by rubbing and banging
> together quartz rocks (which are known to have electrical
> properties). We were able to record very strong "audio like" sounds
> on tape from the radio of our attemps, i.e., we were apparantely
> successful -- way beyond our expectations.
>
> We than tried the same with other "standard" rocks around our
> property. We got weaker, but similar results. We were even able to
> pick up "sounds" from rubbing and banging damp wood sticks together --
> very weak, but still decernable.
>
> The question is: Since we are generating sound waves by our activity
> in the same frequency range as the radio frequencies of the radio,
> could there be some sort of audio coupling going on causing a response
> and recording? This would also seem to follow the pattern with the
> flying insects you mention on your web site. Or do you think we are
> really getting a radio signal from these attempts? Could the fact
> that we are holding the rocks in our hands cause our bodies to act as
> a transmitter of some sort? We put the radio and recorder on a wooden
> post so as to eliminate direct contact with the radio and to try to
> eliminate any possible path through earth ground -- we could still
> pick up recordings. So, as far as we can tell, we are either picking
> up real radio signals or we are causing the radio to respond to the
> sound waves. The fact that the Quartz signal was so strong seems to
> suggest an electrical component was involved.
>
> What do you think? Any suggestion as to how we can be certain it is a
> real radio signal?
>
> Thanks in advance -- we are thoughly enjoying the radio.
>
> Paul & Chantal Boucher

Subject:
VLF information, uploaded INSPIRE STS-45 report
Date:
Mon, 16 Nov 1998 21:11:17 -0800
From:
"Stephen P. McGreevy"

> Hi Steve --
> I tried both URL's and they work nicely. Good!
> I passed along your information to several people here and at South Pole.
> Yeh, I retired and now come in a day per week as a consultant. So I've
> still got e-mail here. Nice life, although I stay as busy as ever.
> Rolf

>
> >Hi Rolf,
> >
> >I now understand that Triax was recently having some down times with
> >their web servers. They're moving shop to a new location in the
> >Portland, OR area. That may explain the access problems with the triax
> >URL's you mentioned in your latest e-mail note. It should be OK now - I
> >checked at a friends machine and it did connect fast, as is normal.
> >
> >IN any case, the info at the vlf.ml.org largely mirrors the Triax site,
> >except for the sound files pages and files--there are much more audio
> >files on the vlf.ml.org site.
> >
> >Thanks much also for the NSF info. I see you're retiring from the NSF.
> >
> >Regards,
> >
> >Steve McGreevy

Subject:
Nasa Inspire program for students
Date:
Fri, 28 Aug 1998 17:54:50 -0700
From:
"Stephen P. McGreevy"

> Aloha < :
>
> I read your article in Amateur radio today magazine and found it very
> interesting. I am a science teacher here in Oakland and I am always
> looking for interesting things to add to my curriculum. If you can
> recommend anything which might be useful from your field my students and
> myself would appreciate it < :
>
> THanks,
>
> Tim Ostrom
> OUSD

-

Subject:
Re: Thank you for the sound!
Date:
Fri, 08 Jan 1999 01:36:24 -0800
From:
"Stephen P. McGreevy"

> Dear Sir/Madam,
>
> Could you please send me details of your vlf receiver (as
> mentioned in Experimental Musical Instruments magazine).

>
> I am also intersted in your work in general so any info.
> would be welcome.
>
> Thanks,
>
> Colin Fallows
> Liverpool John Moores University
> Liverpool Art School
> 68 Hope Street
> Liverpool L1 9EB

Subject:
FW: Radio waves at the planets
Date:
Tue, 06 Apr 1999 21:09:50 -0400
From:
"Payne, Will E"

Your might find Dr Strangeway's answer interesting

> ----------
> From: Robert Strangeway[SMTP:strange@igpp.ucla.edu]
> Reply To: strange@*****.ucla.edu
> Sent: Tuesday, April 06, 1999 7:17 PM
> To: alucier@*****.wesleyan.edu
> Cc: will.e.payne@l*****.com
> Subject: Radio waves at the planets
>
> Dear Mr. Lucier:
>
> Will Payne forwarded an e-mail to me concerning audio recordings of
> radio waves from the Venus, Mars and Mercury. I'd love to help, but these
> planets really are very quiet in terms of radio emissions.
>

> Physically the reason for this is that these planets do not have large

> intrinsic magnetic fields, and so do not have magnetospheres.

> Magnetospheres

> appear to be essential in generating intense radio emissions, since this

> is a means to trap and energize ions and electrons. It is these energetic

> particles that generate the radio waves. The Earth, Jupiter and Saturn

> all have magnetospheres, and all generate radio waves.

>

> The only sources of radio waves at Venus and Mars are the bow shock, where

> the solar wind is deflected around the planet, and from planetary

> lightning.

> Unfortunately, while there was a wave instrument on Pioneer Venus which

> did

> detect these emissions, it really was very limited. We didn't get any

> waveforms, which is what you need to make audio. (The wave instrument is a

>

> narrowly tuned receiver. An analogy might be hearing only middle C, even

> though a full-blooded symphony may be being played.)

>

> No wave receivers have been flown to Mercury, as far as I am aware,

> although

> there should also be emissions from the bow shock. In addition, any radio

> waves from Mercury would be swamped by the Sun, unless you're very close

> to

> the planet.

>

> I'm sorry I can't be of any help in your efforts, but I'll let you know if

> I find out anything more.

>

> Regards,

> Bob Strangeway

MORE TO COME...

S. P. McGreevy
PO Box 928, Lone Pine, California 93545-0928 USA