RADIO MAGiC

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Radio Science: VLF Part 2

Sol Springs to Life!

Beginning in March 2022, a torrent of X-ray solar flares were shot out from an ever increasing number of sunspot regions, including nineteen strong C and M-class flares that hit alternate day sides of the Earth over the Easter long weekend! On 20 April 2022, an X-class X-ray solar flare (X2.25) lit up the central eastern and southern hemispheres during their midday, and the National Oceanic and Atmospheric Association (NOAA) Space Weather Prediction Center (SWPC) issued an R3 level radiation storm alert. My SuperSID receiver system monitors the NPM (Oahu, Hawaii) VLF transmitter plus the NAA, NML and NLK high-powered VLF transmitters in the "lower 48" states, and much to a midnight surprise, my SuperSID receiver detected the NPM SID (shark fin) event occurring nearly 6700 km away (see Figure 1, next page).

VLF radio waves propagate via reflection between the D-region and Earth's surface (day side) and reflection between the E-region and Earth's surface (night side). See Figure 2, next page. It was once believed that they couldn't possibly penetrate the ionosphere and travel into out space but it was recently discovered they do!—More about this later. Higher frequency radio waves experience levels of attenuation up to and including total absorption on the Earth's day side because their skywave components propagate via refraction, spending time and energy travelling through now more heavily ionized and absorptive D and E-regions, and they aren't refracted strongly back to Earth or even refract at all.

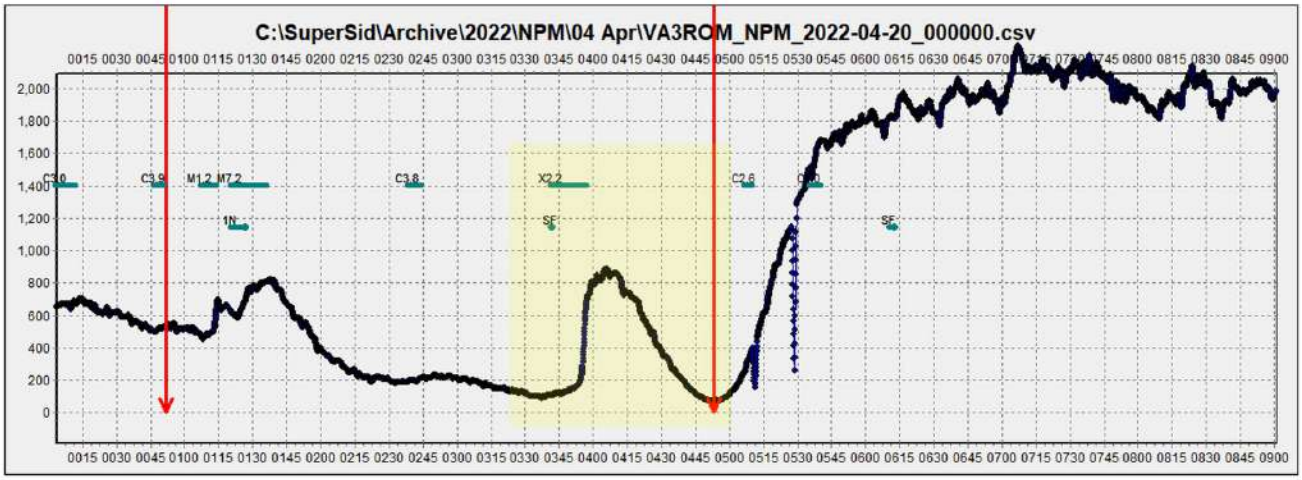

Figure 1: X2.2 X-Ray Solar Flare SID Event (20 April, 0357 UTC)
The SID event captured monitoring the NPM VLF transmitter's signals, which occurred an hour *before* Oahu's local sunset and four hours *after* my local sunset (red arrows).

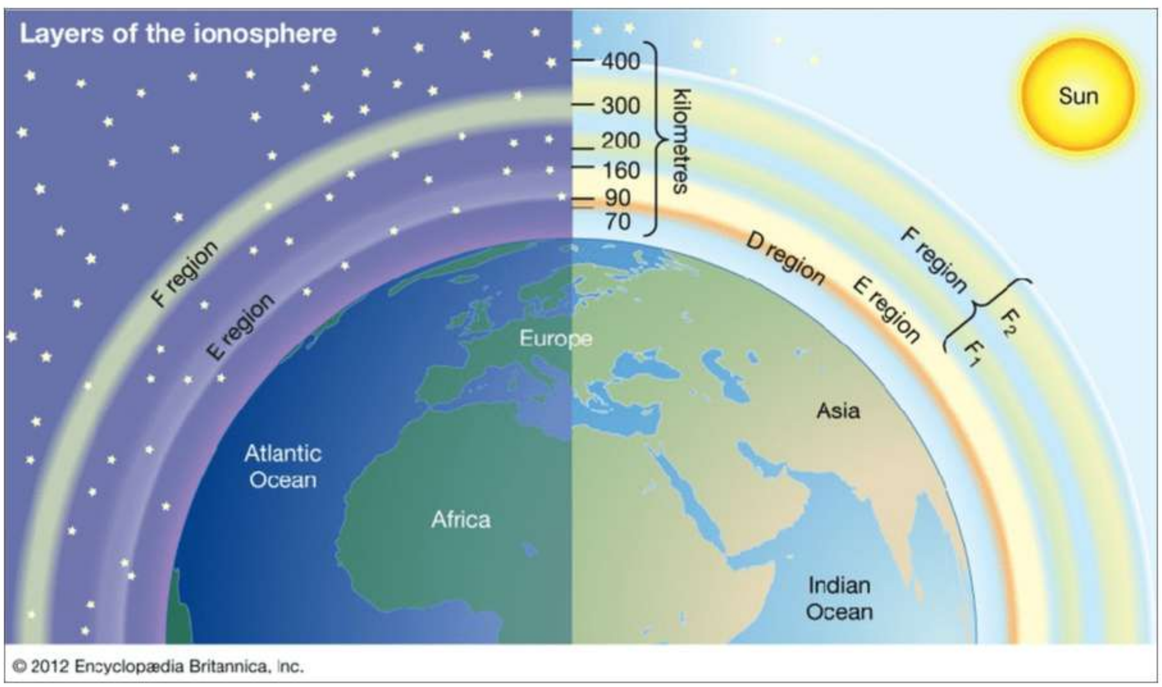

Figure 2: Day and Night Regions of the Ionosphere

SID Software

In early April 2022, I submitted my first SID Data Grabber (SDG) generated report (for March) to the American Association of Variable Star Observers (AAVSO) solar group. An interesting learning experience because it was the first time that I had ever really looked at and analyzed my data. But the SuperSID, SDG and Stanford SOLAR server (see Part 1 article in *TCA* Feb-Mar 2022) process and display all SID events after the fact.

To complicate matters, different y-axis relative signal strength scales are used so it's very difficult to make comparative measurements between any simultaneous SID events without a lot of extra number crunching (Figure 3A).

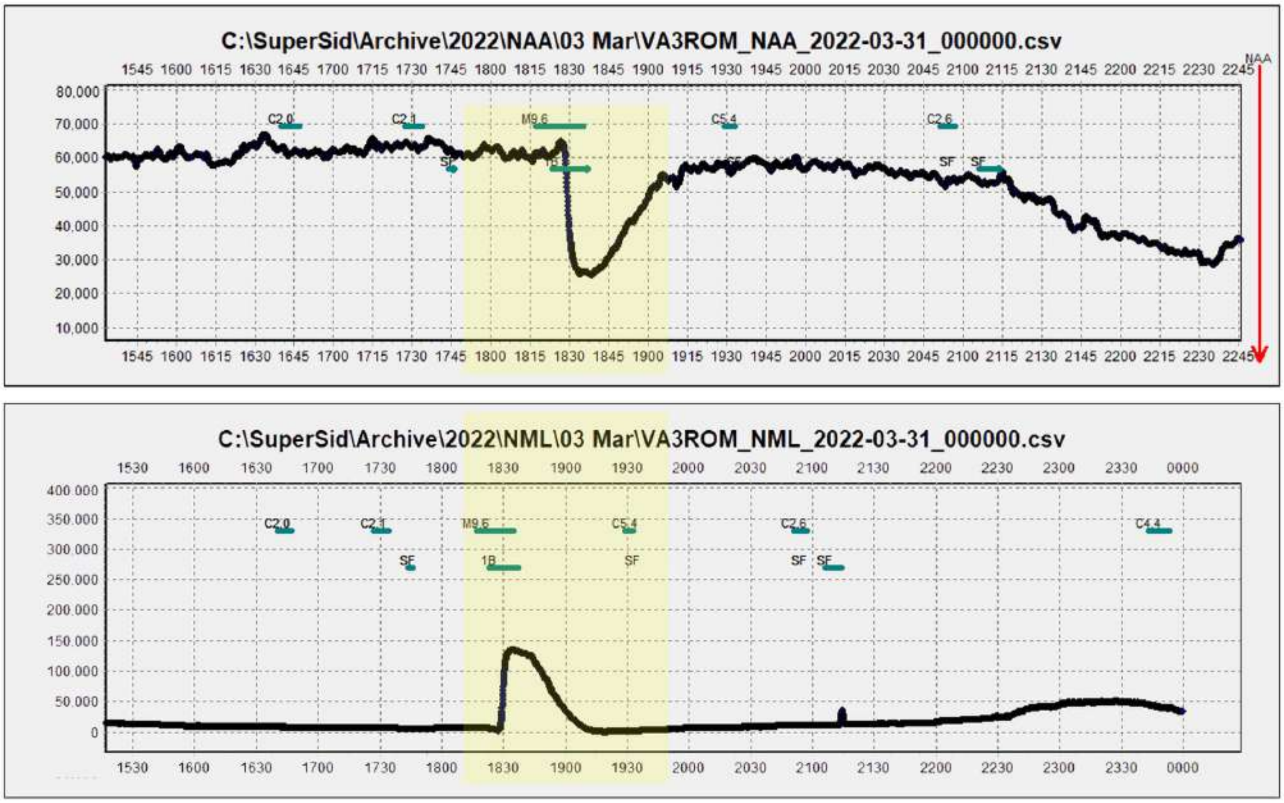

Figure 3A: SDG Processed NAA and NML SID Event (03 March, 1828 UTC)
The NAA (Cutler, Maine) VLF transmitter is 87 solar minutes to my east and depicts an inverted shark fin SID event caused by an M9.6 class X-ray solar flare. The NML (LaMoure, North Dakota) VLF transmitter is only 36 solar minutes to my west (same solar time zone) and depicts the normal upright shark fin. But because two different y-axis scales are used it's very difficult to make comparative measurements between the two SID events.

To solve this problem (to me it was), I modified the stock VLF signal monitoring configuration file supplied with the free audio spectrum analyzer program called "Spectrum Laboratory". It runs alongside the SuperSID program sharing the same sound card VLF signal data, but captures and stores this to a separate CSV file, and creates a real-time VLF signal strength versus time graph of all monitored VLF transmitter signals plus the background atmospheric noise levels measured in decibel-milliwatts (dBm). See Figure 3B, next page.

Simple subtraction of dBm results in comparative dB values; dBm also easily converts to S-units (where -73 dBm equals S9) and vice versa. Now comparisons and measurements using standard units of measurement (dBm and dB) are very easy to make even for me!

Note: I calibrated my sound card's microphone input to produce dBm levels equal to that of a reference receiver's S-meter (KiwiSDR). Or you can just set the input level so that the strongest received day time VLF signal sits around -73 dBm (S9) or so.

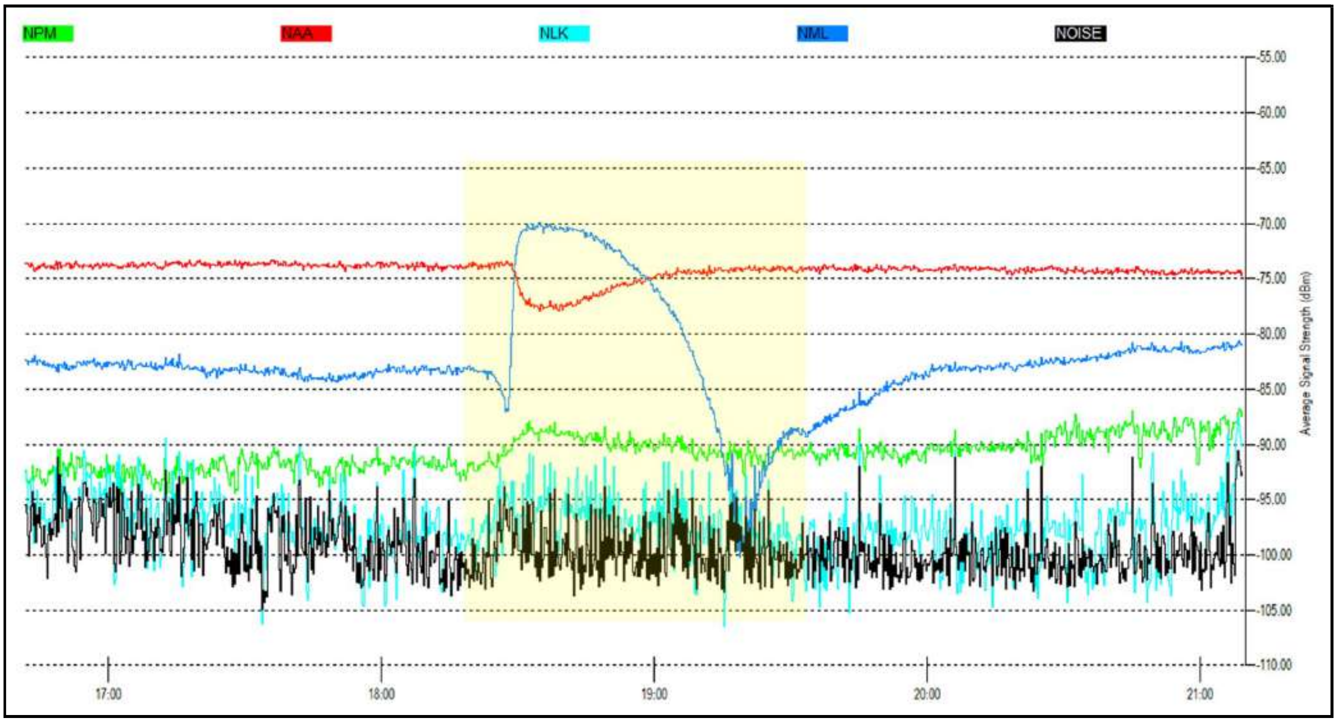

Figure 3B: Spectrum Laboratory Processed SID Event (03 March, 1828 UTC)
Plotting VLF transmitter signals and atmospheric background noise on a Spectrum Laboratory generated real-time plot and using the same signal scale (dBm) for all now makes comparative measurements easy to do. The M9.6 X-ray solar flare had a far greater impact on NML's signal (large upright shark fin) as compared to NAA's (smaller inverted shark fin), but the Figure 2A graphs on the previous page give the opposite and totally wrong impression.

GOES-16

Geostationary operational environment satellite (GOES) dash 16 hovers over a fixed point in space (longitude 75.2 west) with an average altitude of 35,785 km as the Earth rotates below it once a day.

Operated jointly by the National Aeronautics and Space Administration (NASA) and NOAA, besides imaging weather systems it also monitors and records the solar wind's X-ray radiation levels in both "soft" and "hard" energy levels including any X-ray solar flare events, solar extreme ultraviolet radiation (EUV), terrestrial lightening strikes mapping plus measuring Earth's varying magnetic field strength (see Figure 4A). The NOAA SWPC webpage graphs X-ray solar energy levels in real-time and this is can be used to confirm that a suspect SID event in your data was indeed caused by an X-ray solar flare and not by local radio frequency interference (RFI). See Figure 4B, next page. The NOAA SWPC main website also has a plethora of other useful space weather information.

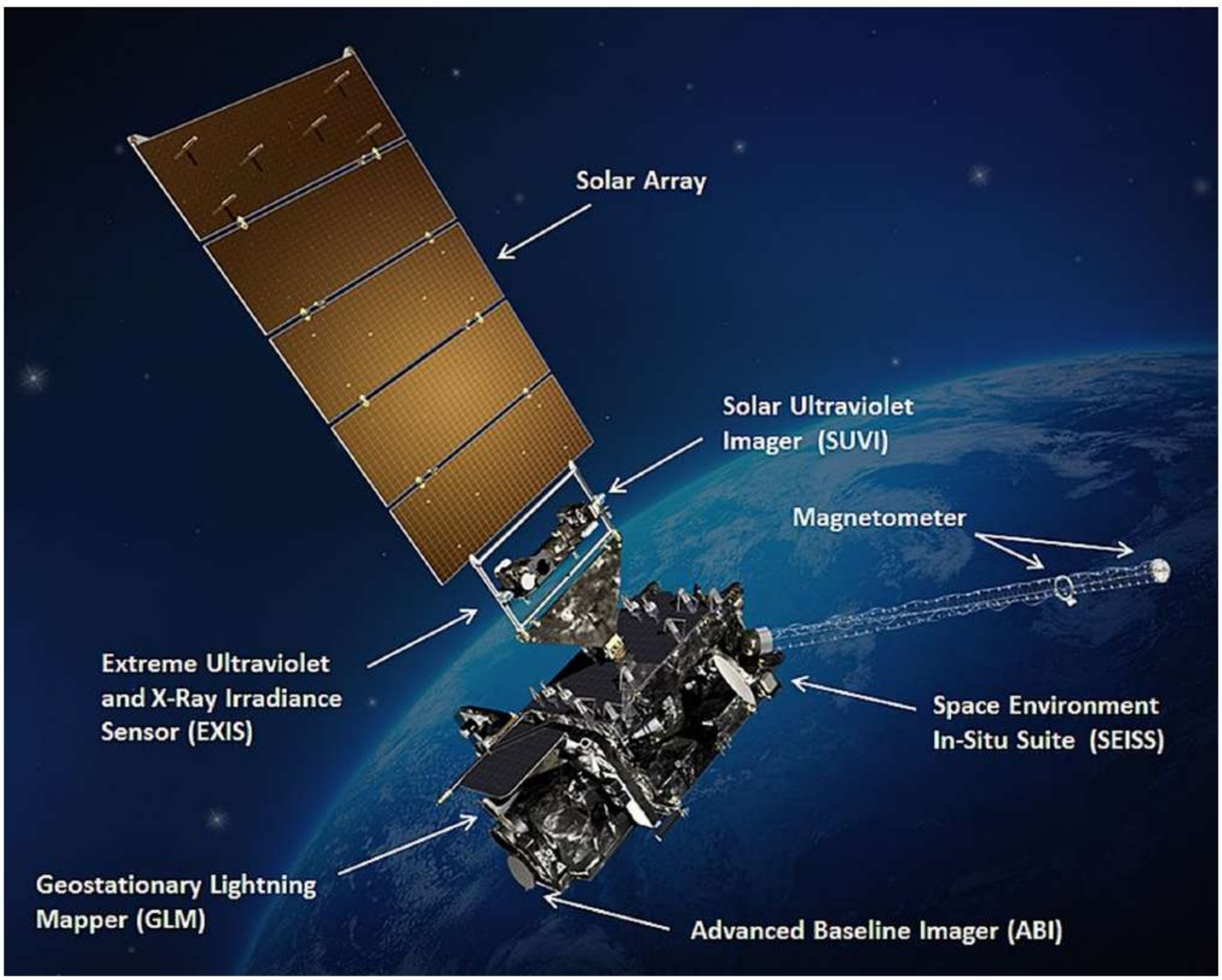

Figure 4A: GEOS-16 Pictorial
Image credit: NASA/NOAA.

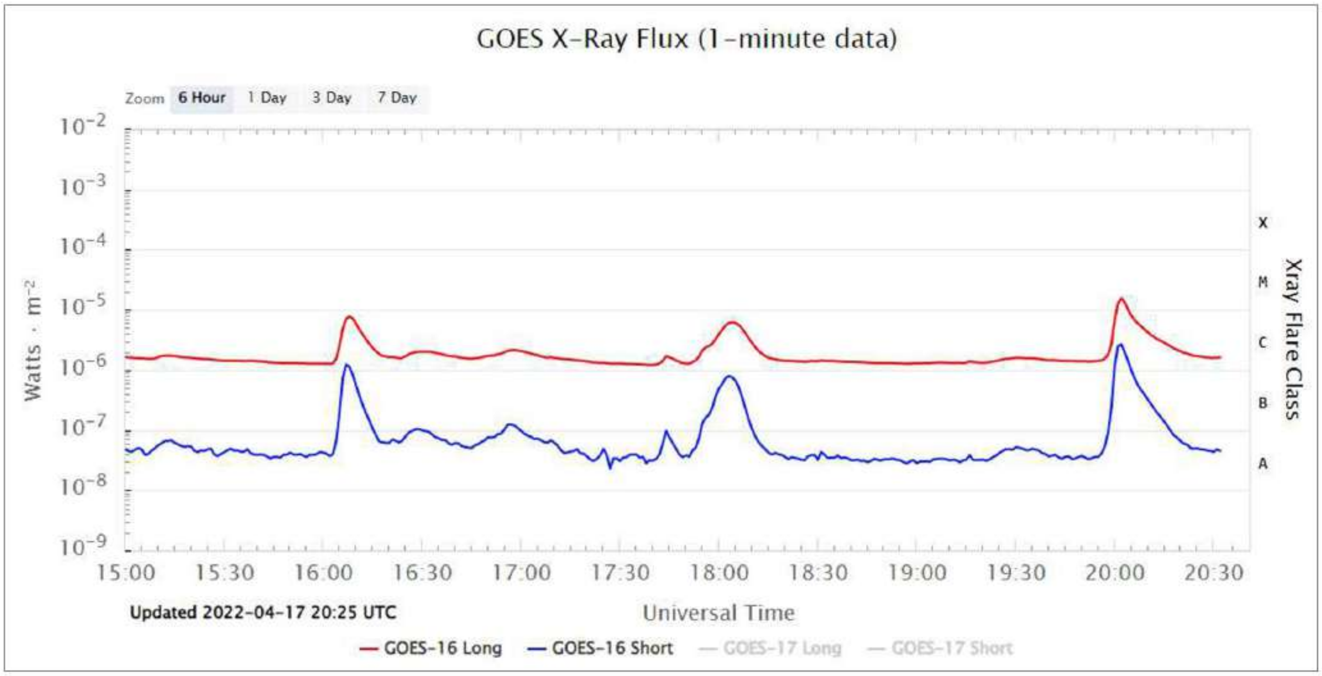

Figure 4B: GOES-16 X-Ray Solar Flux

Three detected X-ray solar flares hit Earth at two hour intervals (two strong C and one weak M-class) on the afternoon of 17 April 2022. All created corresponding SID events in the VLF transmitter signals to my west but *not* NAA's signals to my east for some unknown (to me) reason. Image credit: NASA/NOAA.

Galactic Cosmic Rays (GCR)

GCR are sub-atomic charged particles with intrinsic mass: electrons, hydrogen and helium nuclei (protons and neutrons) plus antiprotons and positrons (antimatter), accelerated to near light speed from many possible sources (especially supernovae) within our own and other galaxies along with weaker cosmic rays emitted by our next door star (the Sun). But cosmic "rays" is actually a misnomer because when they were first detected in 1912 by high altitude weather balloons carrying radiation sensors, they were believed to be electromagnetic (EM) radiation composed of extremely energized photons akin to X-rays and gamma rays. Despite later learning otherwise, the other worldly sounding cosmic ray name stuck once it was popularized by science fiction writers and movies. But I digress…

During solar maxima, our Sun's magnetic shield strengthens and expands to deflect and absorbs enormous amounts of incoming GCR, but it weakens and contracts during solar minima allowing more incoming GCR to flood the inner solar system. Intense GCR bombardments and collisions with our atmosphere's oxygen and nitrogen molecules creates higher levels of the radioactive isotope Beryllium-10 (^{10}Be) along with other particles during solar minima, where it eventually precipitates down and is absorbed by the ground, water, snow and ice layers over the millennia. The radiation exposure risk from GCR during solar minima is increased for those living at or flying at high altitudes. For the past seven years, Californian citizen scientist high school students have been flying high altitude balloons with radiation sensors to track changes in atmospheric (GCR) radiation levels (see Figure 5). It's another great group, club or class research project to carry on through the decades and solar cycles to come.

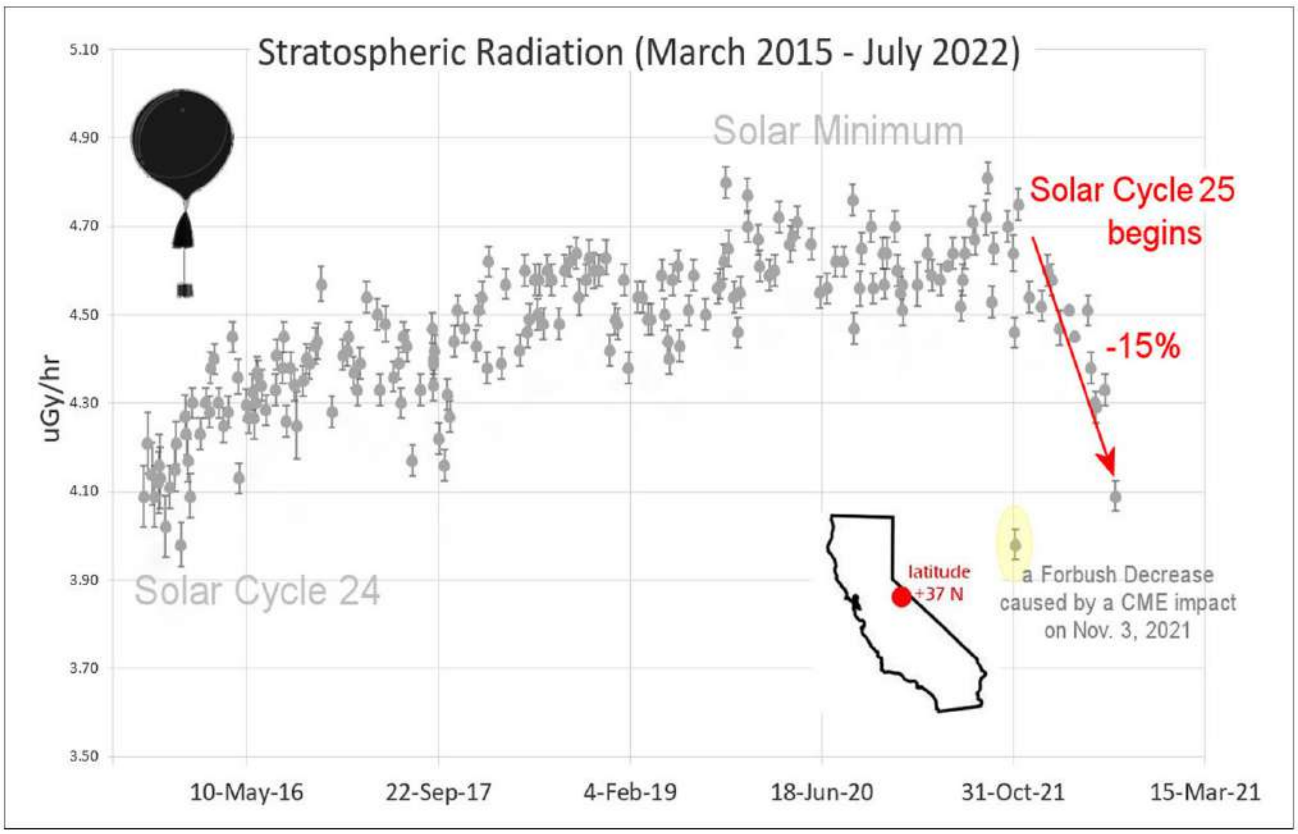

Figure 5: Differences in Minima to Maxima GCR Radiation Levels

During solar cycle 24's minima, GCR atmospheric radiation levels increased until the start of cycle 25. Absorbed dose rate exposure (vertical axis) is in micro-Grays (µGy) per hour (hr). 10 µGy or 0.42 µGy/hr is the average daily dose received from natural background radiation. Space Weather Live (SpaceWeatherLive.com)

Scientists use ice core samples from the Arctic and Antarctica to detect variations in ^{10}BE levels, which can be used as both a global climate change marker and a solar activity proxy. Past GCR bombardments during prolonged solar minima have coincided with past major climate changes (global cooling) that also coincided with major societal changes such the "Homeric" minima circa 800 to 600 BCE (before common era) during the transition from the Bronze to the Iron Age.

Shields Up!

A totally unintended but fortuitous side effect of high-powered, military VLF transmitter use since the 1960's has somehow created a radiation shield or "bubble" around our planet that pushes back against the inner (lower) Van Allen radiation belt (see Figure 6). This shield bubble was only recently discovered by the Van Allen Probes satellites launched in August 2012.

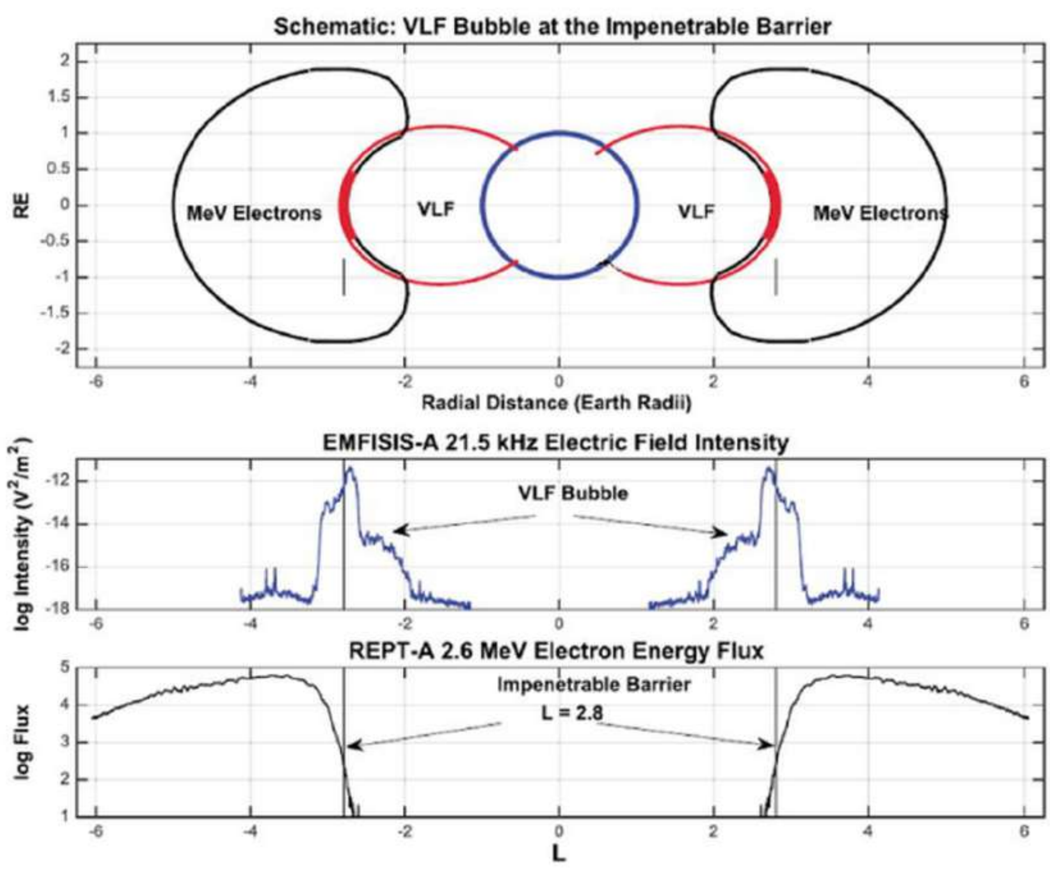

Figure 6: VLF Shield Bubble

Image credit: Foster, J.C. et al, "Observations of the impenetrable barrier, the plasmapause, and the VLF bubble during the 17 March 2015 storm," JGR Space Physics 10.1002/2016JA022509. Information obtained from *The Lowdown* (Mar-Apr 2022); A publication of the Longwave Club of America.

How VLF radio waves (photons) are able to create this protective bubble out to about two Earth radii is to be determined. The Van Allen radiation belts only exist because the solar wind, GCR and other highly energized, charged particles are trapped and held in high orbit by the Earth's magnetosphere, which prevents our atmosphere from being slowly stripped away molecule by molecule leading to the eventual sterilization of the surface as happened to Mars eons ago because of its very, very weak magnetic field. The Earth has its own weak magnetic field region called the "South Atlantic Anomaly" (SAA). See Figure 7. It's an asymmetrical feature where the Earth's magnetic field and therefore magnetosphere are weakest allowing the inner Van Allen radiation belt to drop down to only 200 km! Without the VLF bubble, the inner belt could drop even lower and that would not be a good thing!! Satellites and especially the two space stations China's Tiangong and the International Space Station (ISS) have an extra (thin) layer of shielding to tolerate the few minutes of transits through this region of space.

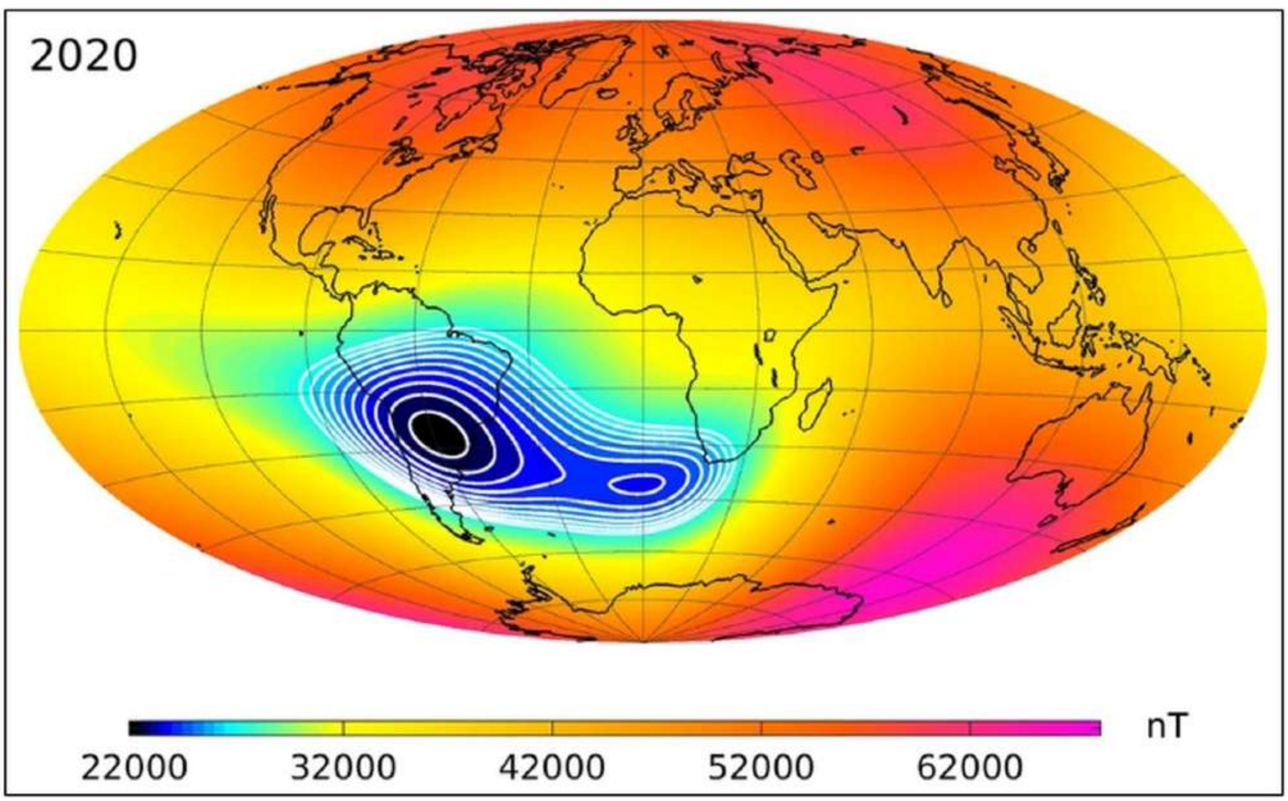

Figure 7: Earth's Magnetic Field and South Atlantic Anomaly (SAA)
GOES-16 measured field strength of Earth's magnetic field in nanotesla (nT). The core of the SAA is over central South America and expanding to the southeast. Image credit: NASA/NOAA.

However, to leave Earth's protective magnetosphere, which only extends out about 90,000 km, and travel in space for a year or so to Mars then live there (if you plan to survive) requires thick and heavy lead plating, meaning extra weight, more fuel and less crew and supplies to make the trip. But in my science fiction future world, now that we know about the VLF bubble we've accidentally created, and what it does to protect us, perhaps high-powered VLF transmitters, generating Star Trek-like radiation/energy deflector shields will one day be carried on planetary spacecraft and installed around future Lunar and Martian colony habitats.

My Final

Well that's it—for now. But there's still much, much more of the EM spectrum that everyone can explore and write about. Quoting well-known Amateur Radio citizen scientist and author Eric P. Nichols, KL7AJ: "Most of the universe interacts with radio in one way or another. In fact, it's almost entirely by radio that scientists are able to probe the farthest reaches of the universe and the smallest building blocks of matter. As Radio Amateurs, we have access to unbelievable wonders of nature that very few 'civilians' can even dream of. We have a vast unexplored playground and you don't need a PhD to enter, just some curiosity and a willingness to look beyond routine radio."—73

References and Resources

Beryllium-10
https://tinyurl.com/bd9j3scj

Cosmic Rays
https://tinyurl.com/4k5wdse9
https://tinyurl.com/4yzzcm9c

Glacial Cycle and Cosmic Rays
Reference: "The Glacial Cycle and Cosmic Rays "; Kirkby, Mangini, Muller. CERN, CH-1211, Geneva, 18 June 2004.

Homeric Minimum
https://tinyurl.com/ycyzxwx3

Earth's Magnetic Field and Magnetosphere
https://tinyurl.com/2bbtcvmb
https://tinyurl.com/4xsmyaps

Earth to Sky Calculus Cosmic Ray Balloon Student Group
https://tinyurl.com/2p97knph

Eric P. Nichols, KL7AJ
Quote from "Amateur Radio Science", *QST*, February 2013, p.77. Used with permission.

Natural Radio and VLF Group
https://groups.io/g/VLF

NOAA SWPC
https://tinyurl.com/yapd2zzk

Radiation Measurement and Shielding Analysis for ISS
https://tinyurl.com/yckkw7yc

Sudden Ionospheric Disturbance
https://tinyurl.com/3rmaynks

Spectrum Laboratory
https://tinyurl.com/mwnkkwrr

Solar Wind
https://tinyurl.com/2p8c7u9s

South Atlantic Anomaly
https://tinyurl.com/2s3hbpbm

Stellar Magnetic Field
https://tinyurl.com/mryw4z4n

Van Allen Radiation Belts
https://tinyurl.com/5s7r399e

Van Allen Probes Satellites
https://tinyurl.com/sktab2nh

VLF Shield Bubble
https://tinyurl.com/3pvfedbr

WSPRnet Archive (March 2008 to Present)
https://tinyurl.com/r87v2jhx